

2009 INSENSITIVE MUNITIONS AND ENERGETIC MATERIALS TECHNOLOGY SYMPOSIUM

"Lower Cost Solutions For 21st Century IM/EM Requirements"

Tucson, AZ

11 - 14 May 2009

Agenda

Tuesday, 12 May 2009

KEYNOTE ADDRESS

• Mr. Ron Carsten, Raytheon

IM OVERVIEW

• Mr. Patrick Touzé, MSIAC

DOD ORDNANCE TECHNOLOGY CONSORTIUM

• Mr. Matthew Beyard, OSD-ATL

Analysis of Throw Distance Produced by a Sub-detonative Munition Response

• Dr. Ernest Baker, US Army RDECOM-ARDEC

2A- IM SYSTEMS I

- Replacement of Octol with IM Explosive in SMAW HEAA Warhead, Carrie Gonzalez, NSWC Indian Head Division
- Common Low-Cost Insensitive Munitions Explosive Replacement for Comp B, Philip Samuels, US Army RDECOM-ARDEC
- 120mm IMHE-T: Effective 120mm IM Solution, Jason Gaines, General Dynamics-OTS
- Linear Demolition Charge Insensitive Munition (IM) Program, Robert Hutcheson, NSWC, Indian Head Division

2B- SYNTHESIS I

- Synthesis and Scale Up of Sym-Triaminotrinitrobenzene (Tatb) at Holston Army Ammunition Plant and Evaluation of PBXN-7 and PBXW-14, David Price, BAE Systems OSI
- Synthesis and Characterization of Nano RDX, Dr. Victor Stepanov, US Army RDECOM-ARDEC
- Process Improvement Studies for Scale-Up of HNS, Jacob Morris, BAE Systems OSI
- Development Toward the Large Scale Synthesis of TEX, Sarah Headrick, ATK
- Comparison Between Polymerization Techniques for Synthesis of Energetic Thermoplastic Elastomers, Khalifa Alkaabi, University of Stellenbosch

3A- MODELING I

- Synthesis and Process Development of NONA: A Highly Thermally Stable Explosive, Dr. David Price, BAE Systems Holston Army Ammunition Plant
- Modeling Fragmentation Performance of Insensitive Explosive Fragmentation Munitions, Vladimir Gold, US Army RDECOM-ARDEC
- New IM Issue on Naval Platforms: Solid Rocket Motor (SRM) Pneumatic Explosion Risk. Effects Prediction Methodology, Nadège Duval, French MoD DGA/CAEPE
- Safety Assessment Of Solid Rocket Motors, Nicolas Couroneau, French MoD/DGA/CAEPE

3B- PROCESSING I

- Press Technology of IHE Charges. A Cost Effective Manufacturing Method for IM, Richard Wild, Diehl BGT Defence
- The Incorporation of New Refining Technologies Within the Existing Nitrocellulose Manufacturing Process at the Radford Army Ammunition Plant, Zachary Higginbotham, Alliant TechSystems Inc.

- Novel Manufacturing Process Development for the High-Blast Explosive PAX-3, Brian Alexander, BAE Systems
- Development And Optimization of a Production Scale Process for the Manufacture of IMX-101 Explosive at Holston Army Ammunition Plan, Curtis Teague, BAE Systems OSI

4A-EXPLOSIVE FORMULATIONS I

- Advances in Cast Cure Explosives, Robert Hatch, ATK Launch Systems
- An Insensitive Substitute for Composition A 3, Christian Spyckerelle, EURENCO
- Development, Optimization, and Application of Combined Effects Explosives, Wendy Balas, US Army RDECOM-ARDEC
- GUNTOL Melt Cast for IM, Per Sjoberg, Eurenco Bofors AB
- Development of Insensitive Aluminized Melt-Pour Explosive, Virgil Fung, BAE Systems

4B- TECHNOLOGY RESOURCES

- South African Navy Prioritisation of Ammunition for Insensitive Munitions (IM) THA and Characterisation, Klaas Steyn, South African Navy
- SA Navy 76mm Ammunition IM Evolution From Prioritisation to Tha to Characterisation and Finally to IM Compliance, Cedric Brijraj, Armscor
- DARTS & HEAT Latest Components of The MSIAC IM Test Responses Databases Suite, Pierre Archambault, MSIAC
- TEMPER: 2009 Development Roadmap, Emmanuel Lapébie, DGA/DET/CEG
- Analyzing Production Processes of Energetic Materials Using Ultrasound Technology, Rajen Patel, US Army RDECOM-ARDEC

Wednesday, 13 May 2009

5A-INGREDIENTS

- Novel Plasticizers for IM compliant Solid Propellants, Ana Racoveanu, Physical Sciences, Inc.
- FOX-7, An IM Ingredient Candidate Where are We Today?, Henric OEstmark, Swedish Defence Research Agency, FOI
- Evaluation of R8002, an Alternate Energetic Plasticizer to BDNP A/F, for use in DOD Munitions (Revised as of 3/17/09), Lilia Mastov, US Army RDECOM-ARDEC
- A New Generation of Binder for Cast PBX, Bernard Mahe, EURENCO France
- Qualify an Alternate Polyisobutylene (PIB) Supplier for Composition C-4 Manufacture, Brad Zastrow, US Army RDECOM-ARDEC

5B- IM SYSTEMS II

- IM Improvements for the MK 22 Mod 4 Rocket Motor, Leandro Garcia, NSWC Indian Head Division
- Propellant Blast Suppressive Transportation Box (PBSTB) a Cost Effective Way to Improve the IMSignature of Rounds Packed in Transport Boxes, Jon Toreheim, Saab Bofors Dynamics AB
- Modeling and Testing of Ceramic Armor Tile Survivability to Fragment Attack, Moran Shpitzer, Rafael
- IM Solutions for Projectiles Crimped to Cartridges for Artillery Application, Phase II, Transition from Cartridge Case Venting to Insensitive Propellant, Carl Campagnuolo, SOCOM
- Bomb Pallet Design for Sympathetic Detonation Abatement of 500 Pound General Purpose Bombs, Neal Lundwall, Naval Air Warfare Center Weapons Division

6A-EXPLOSIVE FORMULATIONS II

- CLX 533, A New Insensitive High Explosive, Eli Shachar, IMI-ISRAEL
- Morphology and Shock Sensitivity in RDX Based Flexible PBX, Chagit Denekamp, Rafael Advanced Defense Systems Ltd.
- Processing Studies of DNAN Based Melt-Pour Explosive Formulations, Pierre Pelletier, GD-OTS Canada
- Insensitive Enhanced Blast Formulations, Philippe Chabin, Eurenco France
- FOX-7 based Insensitive Cast PBX, Christelle Collet, SNPE Materiaux Energetiques

6B- MODELING II

- Modeling of Warhead Response to Projectile Impact with TEMPER Software, Pierre-François Péron, MSIAC
- The Performance of Insensitive Blast Enhanced Explosives, Werner Arnold, MBDA-TDW
- Institute for Multi Scale Reactive Modeling, William Davis, US Army RDECOM-ARDEC
- Design for Insensitive Munitions Compliance of XM1069 120mm Multipurpose Tank Round, David Pfau, US Army RDECOM-ARDEC
- Modeling Methodology for Predicting SCO Performance of the Excalibur Warhead, David Hunter, General Dynamics Ordnance & Tactical Systems

7A-SYNTHESIS II

- Laboratory Scale Nitration of Cellulose as a Cost Effective Risk Mitigation Tool for the Production of Nitrocellulose at Radford Army Ammunition Plant, Benjamin Vaughan, Alliant Tech Systems
- Synthesis and Characterisation of NNHT (2-Nitrimino-5-nitro-hexahydro-1,3,5-triazine), Eamon Colclough,

OinetiO

- Synthesis and Characterization of New Energetic, Insensitive Melt-Pour Candidates, David Price, BAE Systems OSI
- Characterization of Existing Stockpile and Development of Synthetic Calcium Disilicide, Paul Anderson, US Army RDECOM-ARDEC
- 1, 2, 4-Butanetriol Production at ATK A Sustainable Solution, Steve Velarde, ATK Energetic Systems

7B-TESTING I

- Qualification Testing of the Insensitive TNT Replacement Explosive IMX-101, Anthony Di Stasio, US Army RDECOM-ARDEC
- Qualification of ITEX-07 Explosive for Fuze Applications, Rainer Schirra, DyniTEC
- Studies of HBU88B manufactured with CONUS RDX, Pierre Pelletier, GD-OTS Canada
- Mitigation of Thermal Threats to Rocket Motors by Venting Devices Driven by Contracting Shape Memory Alloy Wire, John Cook, QinetiQ
- Fragment Impact Studies of Complete and Sectioned Rocket Motors, Peter Haskins, QinetiQ Ltd

8A-PROPELLANTS

- Qualitative Evaluation of Response of LOVA Gun Propellant Charge by Bullet Impact and Cook-Off, Jun Maruyama, Ground Systems Research Center, GSRC, TRDI, MOD
- Insensitive Munitions (IM) Testing: 25mm Target Practice, Discarding Sabot with Trace (TPDS-T), M910 Cartridge using ECL Propellant, Bishara Elmasri, US Army RDECOM-ARDEC
- Army Advanced Gun Propellant Formulations, Thelma Manning, US ARMY RDECOM ARDEC
- A Stable Liquid Mono Propellant based on ADN, Per Sjoberg, Eurenco Bofors AB
- Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination (RIGHTTRAC) Technology Demonstrator Program, Patrick Brousseau, DRDC Valcartier

8B-TECHNOLOGY

- Managing the Development and Capability Investment of the IM Development Programs Through Science and Technology and Munitions Requirements, Ken Tomasello, Naval Sea Systems Command
- High Rate Thermal Analysis of Propellant Based Cook-Off Mitigants, Duncan Langlois, ATK Energetics Systems
- Characterization of the ageing of HTPB Binder based insensitive high explosive charge by Heat Flow Microcalorimetry, Chemiluminescence, GAP test and Dynamic Mechanical Analysis, Manfred Bohn, Fraunhofer Institut Chemische Technologie, ICT
- Production of Aluminum Metal Matrix Composite Cases for Insensitive Munitions Testing, Brian Gordon, Touchstone Research Laboratory

Thursday, 14 May 2009

9A-TESTING II

- Accelerated Ageing Study of Low Sensitivity PBX Formulation FPX V40, Mari-Ella Sairiala, PVTT
- Roxel IM Technology, Analysis of Trial Results, Future IM Programmes in France and UK, Jean Claude Nugeyre, ROXEL
- IM Response for Army Engineering Charges Based on FPX V40, Hannu Hytti, OY FORCIT AB
- New Cost Effective Test Methods Within the IM Program, Rickard Lindström, Saab Bofors Test Center AB
- Update on HTPE Propellant Service Life, , Ted Comfort, ATK Mission Systems

9B- PROCESSING II

- Temperature Independant Gun Propellants Based on NC and DNDA For IM Ammunition, Dietmar Mueller, Fraunhofer Institut Chemische Technologie (ICT)
- Co-Extrusion of Gun Propellants, Martijn Zebregs, TNO Defence, Security and Safety
- Scale-up Of Energetic Nitrate Salts For Insensitive DEMN Formulations, Sarah Headrick, ATK

10A- EXPLOSIVE FORMULATION III

- Tailored Sensitivity Explosive Formulations, Bruno Nouguez, EURENCO France
- Comp B Explosive Replacement Development, Robert Hatch, ATK Launch Systems
- Recent Developments in Composition C-4: Towards an Alternate Binder and Reduced Sensitivity, James Owens, BAE Systems
- Experimental Deviations from Conventional Critical Temperature Models for Non-ideal Explosive Formulations, Brian Roos, U.S. Army Research Laboratory

10B- IM/EM ISSUES

- Pyrotechnic Mixture Substition for Explosives, Randall Busky, ATK Armament Systems Lake City
- Thermal Analysis of IMX-101 Through Large Scale Slow Cook Off Testing, Alberto Carrillo, BAE Systems OSI
- IM Response Descriptors an Update for Assessment Processes, Thomas Swierk, NSWC Dahlgren
- FITS, Finnish IM Technology Study, Kosti Nevala, Patria Land & Armament



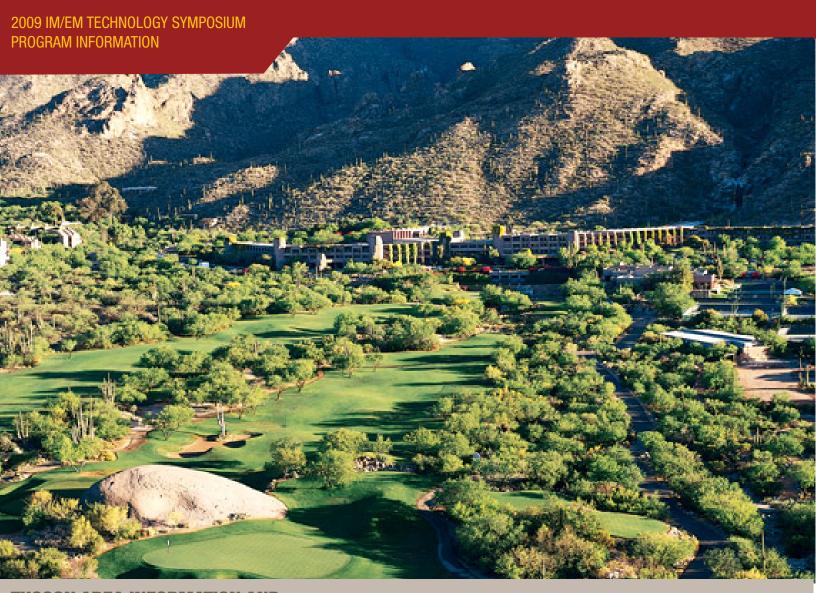




LOWER COST SOLUTIONS FOR 21ST CENTURY IM/EM REQUIREMENTS



WWW.NDIA.ORG/MEETINGS/9550



TUCSON AREA INFORMATION AND LOEWS VENTANA CANYON RESORT

Things to do...

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Visit http://www.visittucson.org/

Loews Ventana Canyon Resort...

Hotel Features:

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Fore more information on the Loews Ventana Canyon Resort, visit www.loewshotels.com/en/Hotels/Tucson-Resort/Overview.aspx

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- **ONE SOLD TO IMEMG**
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- COMPANY DESCRIPTION (300 WORDS) AND LOGO IN ON-SITE MATERIALS
- COMPANY NAME ON COCKTAIL NAPKINS AT THE RECEPTION
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- EVENT SPECIFIC SIGNAGE THROUGHOUT CONFERENCE

DINNER SPONSOR (AVAILABLE TO 2 SPONSORS)......INVESTMENT: \$10,000 @ OR \$20,000 ALONE

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- EVENT SPECIFIC SIGNAGE THROUGHOUT CONFERENCE

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- SPONSOR RIBBONS ON DESIGNATED BADGES
- EVENT SPECIFIC SIGNAGE AND THROUGHOUT CONFERENCE
- LOGO IN THE CONFERENCE ON-SITE MATERIALS

BREAK AREA SPONSOR (AVAILABLE TO 5 SPONSORS).....INVESTMENT: \$4,000 PER BREAK

- LIGHT REFRESHMENTS FOR CONFERENCE ATTENDEES DURING BREAKS (TO INCLUDE COFFEE, TEA, SODAS AND WATER)
- SPONSOR RIBBONS ON DESIGNATED BADGES
- EVENT SPECIFIC SIGNAGE AND THROUGHOUT CONFERENCE
- LOGO IN THE CONFERENCE ON-SITE MATERIALS

LUNCH SPONSOR (AVAILABLE TO 2 SPONSORS)......INVESTMENT: \$12,000 PER LUNCH

ONE SOLD TO NTS

- COMPANY NAME OR LOGO ON SIGNAGE AT EACH LUNCH TABLE
- 10-SLIDE CONTINUOUS LOOP POWER POINT PRESENTATION TO BE SHOWN PRIOR TO LUNCHEON SPEAKER
- COMPANY DESCRIPTION (300 WORDS) AND LOGO IN THE CONFERENCE ON-SITE MATERIALS
- SPONSOR RIBBONS ON DESIGNATED BADGES
- EVENT SPECIFIC SIGNAGE THROUGHOUT CONFERENCE

FOR MORE INFORMATION ON SPONSORSHIP OPPORTUNITES OR TO PURCHASE A SPONSORSHIP, PLEASE CONTACT JENNIFER HOECHST, MEETING PLANNER AT JHOECHST@NDIA.ORG

MONDAY, MAY 11

4:30 pm - 7:00 pm REGISTRATION OPENS 5:30 pm - 7:00 pm OPENING RECEPTION

TUESDAY, MAY 12

7:00 am - 8:00 am CONTINENTAL BREAKFAST

8:00 am - 8:10 am WELCOME REMARKS

Conference Chair: Mr. Steven Nicolich, US Army RDECOM-ARDEC

8:10 am - 8:40 am KEYNOTE ADDRESS

Mr. Ron Carsten, Raytheon

8:40 am - 9:05 am MSIAC AWARDS

Mr. Patrick Touzé, MSIAC

9:05 am - 9:25 am IM OVERVIEW

Mr. Patrick Touzé, MSIAC

9:25 am - 9:40 am DOD ORDNANCE TECHNOLOGY CONSORTIUM

Mr Matthew Beyard, OSD-ATL

9:40 am - 10:00 am ANALYSIS OF THROW DISTANCE PRODUCED BY A SUB-DETONATIVE MUNITION RESPONSE

Dr. Ernest Baker, US Army RDECOM-ARDEC

10:00 am - 10:30 am BREAK

2A- IM Systems I

Session Chair: Stephen Struck, USAF-Eglin

10:30 AM Replacement of Octol with IM Explosive in SMAW HEAA Warhead

Carrie Gonzalez, NSWC Indian Head Division

10:50 AM Common Low-Cost Insensitive Munitions Explosive Replacement for Comp B

Philip Samuels, US Army RDECOM-ARDEC

11:10 AM 120mm IMHE-T: Effective 120mm IM Solution

Jason Gaines, General Dynamics-OTS

11:30 AM Linear Demolition Charge Insensitive

Munition (IM) Program

Robert Hutcheson, NSWC, Indian Head Division

11:50 AM The 155mm LU211 IM, an Example of IM

Implementation

Régis Aumasson, NEXTER Munitions

2B- Synthesis I

Session Chair: Andrew Sanderson, ATK

10:30 AM Synthesis and Scale Up of Sym-

Triaminotrinitrobenzene (Tatb) at Holston Army Ammunition Plant and Evaluation of PBXN-7 and

PBXW-14

David Price, BAE Systems OSI

10:50 AM Towards The Synthesis of Organic Nanoenergetic

Compositions

Anne Keromnes-Wuillaume, CEA

11:10 AM Process Improvement Studies for Scale-Up of HNS

Jacob Morris, BAE Systems OSI

11:30 AM Development Toward the Large Scale Synthesis of

TEX

Sarah Headrick, ATK

11:50 AM Comparison Between Polymerization Techniques

for Synthesis of Energetic Thermoplastic

Elastomers

Khalifa Alkaabi, University of Stellenbosch

12:10 pm - 1:40 pm SIT DOWN LUNCHEON IN GRAND BALLROOM

3A- Modeling I

Session Chair: Ernie Baker, US Army RDECOM - ARDEC

1:40 PM Using a Single Phase FEM Code to Model Phase Change During SCO Analysis David Hunter, General Dynamics Ordnance and Tactical Systems

2:00 PM Modeling Fragmentation Performance of Insensitive Explosive Fragmentation Munitions Vladimir Gold, US Army RDECOM-ARDEC

2:20 PM New IM Issue on Naval Platforms: Solid Rocket Motor (SRM) Pneumatic Explosion Risk. Effects Prediction Methodology.
Nadège Duval, French MoD DGA/CAEPE

2:40 PM Safety Assessment Of Solid Rocket Motors Nicolas Couroneau, French MoD/DGA/CAEPE

3B- Processing I

Session Chair: Andrew Wilson, Esterline ARMTEC Defense

1:40 PM Press Technology of IHE Charges. A Cost Effective Manufacturing Method for IM.
Richard Wild, Diehl BGT Defence

2:00 PM The Incorporation of New Refining Technologies Within the Existing Nitrocellulose Manufacturing Process at the Radford Army Ammunition Plant Zachary Higginbotham, Alliant TechSystems Inc.

2:20 PM Novel Manufacturing Process Development for the High-Blast Explosive PAX-3
Brian Alexander, BAE Systems

2:40 PM Development And Optimization of a Production Scale Process for the Manufacture of IMX-101 Explosive at Holston Army Ammunition Plan Curtis Teague, BAE Systems OSI

3:00 pm - 3:20 pm BREAK

4A- Explosive Formulations I

Session Chair: Paul Braithwaite, ATK

3:20 PM Advances in Cast Cure Explosives Robert Hatch, ATK Launch Systems

3:40 PM An Insensitive Substitute for Composition A 3 Christian Spyckerelle, EURENCO

4:00 PM Development, Optimization, and Application of Combined Effects Explosives
Wendy Balas, US Army RDECOM-ARDEC

4:20 PM GUNTOL - Melt Cast for IM Per Sjoberg, Eurenco Bofors AB

4:40 PM Development of Insensitive Aluminized Melt-Pour Explosive
Virgil Fung, BAE Systems

4B- Technology Resources

Session Chair: Melissa Hobbs, GD-OTS

3:20 PM South African Navy Prioritisation of Ammunition for Insensitive Munitions (IM) THA and Characterisation

Klaas Steyn, South African Navy

3:40 PM SA Navy 76mm Ammunition IM Evolution From Prioritisation to Tha to Characterisation and Finally to IM Compliance Cedric Brijraj, Armscor

4:00 PM DARTS & HEAT - Latest Components of The MSIAC IM Test Responses Databases Suite Pierre Archambault, MSIAC

4:20 PM TEMPER : 2009 Development Roadmap Emmanuel Lapébie, DGA/DET/CEG

4:40 PM Analyzing Production Processes of Energetic Materials Using Ultrasound Technology Rajen Patel, US Army RDECOM-ARDEC

5:30 pm - 6:30 pm RECEPTION

6:30 pm DINNER

Invited Guest Speaker: Dr. Peter Smith, University of Arizona, Phoenix Mars Mission

WEDNESDAY, MAY 13

7:00 am - 8:00 am CONTINENTAL BREAKFAST

5A- Ingredients				
Session Chair: Heather Gokee, NSWC- Indian Head				
MA 00:8	Novel Plasticizers for IM compliant Solid Propellants Ana Racoveanu, Physical Sciences, Inc.			
8:20 AM	FOX-7, An IM Ingredient Candidate - Where are We Today?			
	Henric OEstmark, Swedish Defence Research Agency, FOI			
8:40 AM	Evaluation of R8002, an Alternate Energetic Plasticizer to BDNP A/F, for use in DOD Munitions (Revised as of 3/17/09) Lilia Mastov, US Army RDECOM-ARDEC			
9:00 AM	A New Generation of Binder for Cast PBX Bernard Mahe, EURENCO France			
9:20 AM	Qualify an Alternate Polyisobutylene (PIB) Supplier for Composition C-4 Manufacture Brad Zastrow, US Army RDECOM-ARDEC			

5B- IM Systems II

Session Chair: Brian Fuchs, US Army RDECOM-ARDEC

8:00 AM IM Improvements for the MK 22 Mod 4 Rocket Motor Leandro Garcia, NSWC Indian Head Division

8:20 AM Propellant Blast Suppressive Transportation Box (PBSTB) - a Cost Effective Way to Improve the IM-Signature of Rounds Packed in Transport Boxes Jon Toreheim, Saab Bofors Dynamics AB

8:40 AM Modeling and Testing of Ceramic Armor Tile Survivability to Fragment Attack Moran Shpitzer, Rafael

9:00 AM IM Solutions for Projectiles Crimped to Cartridges for Artillery Application, Phase II, Transition from Cartridge Case Venting to Insensitive Propellant Carl Campagnuolo, SOCOM

9:20 AM Managing the Development and Capability
Investment of the IM Development Programs
Through Science and Technology and Munitions
Requirements
Ken Tomessello, Naval Sea Systems Command

6B- Modeling II

9:40 am - 10:00 am BREAK

6A- Explosive Formulations II

Session Chair: Wendy Balas, US Army RDECOM- ARDEC

10:00 AM CLX 533, A New Insensitive High Explosive Eli Shachar, IMI-ISRAEL

10:20 AM Morphology and Shock Sensitivity in RDX Based Flexible PBX

Chagit Panakama Rafael Advanced Ref.

Chagit Denekamp, Rafael - Advanced Defense Systems Ltd.

10:40 AM Processing Studies of DNAN Based Melt-Pour Explosive Formulations

Pierre Pelletier, GD-OTS Canada

11:00 AM Insensitive Enhanced Blast Formulations Philippe Chabin, Eurenco France

11:20 AM FOX-7 based Insensitive Cast PBX
Christelle Collet, SNPE Materiaux Energetiques

Explosives Werner Arnold, MBDA-TDW

Session Chair: Peter Haskins, QinetiQ

10:40 AM Institute for Multi Scale Reactive Modeling William Davis, US Army RDECOM-ARDEC

10:00 AM Modeling of Warhead Response to Projectile

10:20 AM The Performance of Insensitive Blast Enhanced

Impact with TEMPER Software

Pierre-François Péron, MSIAC

11:00 AM Design for Insensitive Munitions Compliance of XM1069 120mm Multipurpose Tank Round David Pfau, US Army RDECOM-ARDEC

11:20 AM Modeling Methodology for Predicting SCO Performance of the Excalibur Warhead David Hunter, General Dynamics Ordnance & Tactical Systems

11:40 am - 1:00 pm LUNCH

7A- Synthesis II

Session Chair: Per Sjoberg, Eurenco Bofors AB

- 1:00 PM Laboratory Scale Nitration of Cellulose as a Cost Effective Risk Mitigation Tool for the Production of Nitrocellulose at Radford Army Ammunition Plant Benjamin Vaughan, Alliant Tech Systems
- 1:20 PM Synthesis and Characterisation of NNHT (2-Nitrimino-5-nitro-hexahydro-1,3,5-triazine) Eamon Colclough, QinetiQ
- 1:40 PM Synthesis and Characterization of New Energetic, Insensitive Melt-Pour Candidates David Price, BAE Systems OSI
- 2:00 PM Characterization of Existing Stockpile and Development of Synthetic Calcium Disilicide Paul Anderson, US Army RDECOM-ARDEC
- **2:20 PM** Butane Triol Synthesis and Manufacture Will Tilford, BAE Systems OSI

7B- Testing I

Session Chair: Kenneth Graham, Aerojet

- 1:00 PM Qualification Testing of the Insensitive TNT Replacement Explosive IMX-101 Kenneth Lee, US Army RDECOM-ARDEC
- 1:20 PM Qualification of ITEX-07 Explosive for Fuze Applications
 Rainer Schirra, DyniTEC
- **1:40 PM** Studies of HBU88B manufactured with CONUS RDX Pierre Pelletier, GD-OTS Canada
- 2:00 PM Low Velocity Impact Testing and Simulation on Generic Munitions
 Gert Scholtes, TNO Defence, Security and Safety
- 2:20 PM Fragment Impact Studies of Complete and Sectioned Rocket Motors Malcolm Cook, QinetiQ Ltd

2:40 pm - 3:00 pm BREAK

8A- Propellants

Session Chair: Nora Eldredge, US Army Research Laboratory

- **3:00 PM** Qualitative Evaluation of Response of LOVA Gun Propellant Charge by Bullet Impact and Cook-Off Jun Maruyama, Ground Systems Research Center, GSRC, TRDI, MOD
- 3:20 PM Insensitive Munitions (IM) Testing: 25mm Target Practice, Discarding Sabot with Trace (TPDS-T), M910 Cartridge using ECL Propellant Bishara Elmasri, US Army RDECOM-ARDEC
- **3:40 PM** Army Advanced Gun Propellant Formulations Thelma Manning, US ARMY RDECOM ARDEC
- **4:00 PM** A Stable Liquid Mono Propellant based on ADN Per Sjoberg, Eurenco Bofors AB
- 4:20 PM Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination (RIGHTTRAC) Technology Demonstrator Program
 Patrick Brousseau, DRDC Valcartier

8B- Technology

Session Chair: Pierre-François Péron, MSIAC

- 3:00 PM Slow Cookoff Testing of a Thermally Activated Venting System

 Michael Fisher, Cornerstone Research Group, Inc.
- 3:20 PM High Rate Thermal Analysis of Propellant Based Cook-Off Mitigants
 Duncan Langlois, ATK Energetics Systems
- **3:40 PM** Using Energetic Materials to Control Warhead Ignition During Slow Cook-Off Nausheen Al-Shehab, US Army RDECOM-ARDEC
- **4:00 PM** Metal Matrix Composite (MMC) Solid Rocket Motor Demonstration
 Matt Shewmaker, NAWCWD China Lake, CA
- **4:20 PM** Production of Aluminum Metal Matrix Composite Cases for Insensitive Munitions Testing Brian Gordon, Touchstone Research Laboratory

4:40 pm ADJOURN FOR THE DAY

THURSDAY, MAY 14

7:30 am - 8:30 am CONTINENTAL BREAKFAST

	9A- Testing II
Session Cl	nair: Tim Mahoney, NAWC- China Lake
8:30 AM	Accelerated Ageing Study of Low Sensitivity PBX Formulation - FPX V40
8:50 AM	Mari-Ella Sairiala, PVTT Roxel IM Technology, Analysis of Trial Results, Future IM Programmes in France and UK. Jean Claude Nugeyre, ROXEL
9:10 AM	IM Response for Army Engineering Charges Based of FPX V40 Hannu Hytti, OY FORCIT AB
9:30 AM	New Cost Effective Test Methods Within the IM Program Rickard Lindström, Saab Bofors Test Center AB
9:50 AM	Development of Novel Launcher for Fragment Impact Test Vincent Tanguay, Defence R&D Canada

	9B- Processing II
Session C	hair: Scott McDonald, US Army RDECOM-ARDEC
8:30 AM	Temperature Independant Gun Propellants Based on NC and DNDA For IM Ammunition
	Dietmar Mueller, Fraunhofer Institut Chemische Technologie (ICT)
8:50 AM	Co-Extrusion of Gun Propellants
	Martijn Zebregs, TNO Defence, Security and Safety
9:10 AM	Foamable Celluloid Compositions for Enhanced Combustion Characteristics and Low Temperature Performance
	Elbert Caravaca, US Army RDECOM-ARDEC
9:30 AM	Scaleup Of Energetic Nitrate Salts For Insensitive DEMN Formulations Sarah Headrick, ATK
9:50 AM	Enhanced Production Capabilities for IM Explosive Ingredients Using the Agile Manufacturing Facility at Holston Army Ammunition Plant

Mike Ervin, BAE Systems

10:10 am - 10:30 am BREAK

1	OA- Explosive Formulation III		10B- IM/EM Issues
Session Ch	air: Paul Wanninger, IMEMG	Session Ch	nair: Matt Beyard, OSD- ATL
10:30 AM 10:50 AM	Robert Hatch, ATK Launch Systems	10:30 AM	Pyrotechnic Mixture Substition for Explosives Randall Busky, ATK Armament Systems Lake Ci Thermal Analysis of IMX-101 Through Large Sca Slow Cook Off Testing Alberto Carrillo, BAE Systems OSI
11:10 AM	an Alternate Binder and Reduced Sensitivity James Owens, BAE Systems	11:10 AM	•
11.30 AM	Experimental Deviations from Conventional Critical Temperature Models for Non-ideal Explosive Formulations Brian Roos, U.S. Army Research Laboratory	11:30 AM	FITS, Finnish IM Technology Study Kosti Nevala, Patria Land & Armament

1:00 pm **GOLF OUTING** *MUST PRE- REGISTER FIRST AS THERE ARE LIMITED SPOTS AVAILABLE

IMEM Golf Tournament - May 14, 2009 1:00 pm

Ventana Canyon Golf Course
Price per golfer \$100.00 • Only 48 slots available!

(Price includes green fees, cart, prizes and awards reception)
Rental clubs are available for \$60.50

Send Checks and Registration Form To:
Attn: Karen Stasell, GD-OTS (make checks payable to GD-OTS)
11399 16th Ct, Suite 200
St. Petersburg, FL 33716
(ph)727-432-0809
kstasell@gd-ots.com

lame:				
Rental Clubs (\$60.50): Left	t handed	Right hande	d	
oursome:				
Player:2	Renta	l Clubs: Left h	anded	_Right handed_
Player:3	Renta	ıl Clubs: Left h	anded	_Right handed_
Player:4	Renta	ıl Clubs: Left h	anded	_Right handed_
Company:		_		
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Pity:	State:	Zip:	_	
elephone:	Fax:		Email:	
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REGISTRATION

ONLINE:

Our preferred method of registration is online. Visit http://www.ndia.org/meetings/9550 to register today.

FAX:

Register via fax by completing the Registration Form and faxing it to (703) 522-1885. Please do not fax any registrations after April 27, 2009.

HOTEL INFORMATION

A limited number of rooms have been reserved at The Loews Ventana Canyon Resort, Tucson AZ. To make a reservation, call 1-800-234-5117 and ask for the "National Defense Industrial Association IM/EM" conference room block. The cutoff date for accepting reservation into this block is April 17, 2009, but rooms may sell out before then.

TRANSPORTATION

The hotel is not located near the airport. Taxi rides cost approximately \$60, and allow up to 4 passangers to split the cost. It is recommended to share rides. Taxi stands are located right outside the airport, as well as shuttles and vans.

CONFERENCE REGISTRATION FEES	EARLY (BEFORE 4/11)	REGULAR	LATE (AFTER 5/1)
GOVERNMENT/ ACADEMIA/ ALLIED GOV.	\$535	\$590	\$650
INDUSTRY NDIA MEMBER	\$740	\$815	\$895
INDUSTRY Non-Ndia member	\$785	\$865	\$950
SPEAKER	\$535	\$590	\$650

MAIL:

Registration forms may be mailed to: NDIA, Event #9380, 2111 Wilson Blvd., Suite 400, Arlington, VA 22201. Please do not mail any registrations after April 27, 2009. Registrations will not be taken over the phone. Payment must be made at the time of registration.

ATTENDEE ROSTER

An attendance roster will be distributed at the conference. Your registration form and payment must be received April 27, 2009 to be included in the roster. An updated roster will NOT be printed after the conference.

CANCELLATION POLICY

Cancellations before 4/11/09 receive a full refund. Cancellations between 4/11/09-4/30/09 receive a refund minus a \$75 cancellation fee. No refunds for cancellations received on/after 5/1/09. Cancellations must be made in writing. Substitutions welcome in lieu of cancellations. Please e-mail your cancellations or substitutions to Jennifer Hoechst via email: jhoechst@ndia.org

CONFERENCE ATTIRE

The appropriate attire for this conference is business casual attire or Military Class B uniform.

SPECIAL NEEDS

NDIA is supports the Americans with Disabilities Act of 1990. Attendees with Special Needs should contact Jennifer Hoechst by March 10, 2009 via email: jhoechst@ndia.org d refer to the Insensitive Munitions and Energetic Materials Conference.

INQUIRIES:

For more information, contact Jennifer Hoechst, Meeting Planner, NDIA, at 703-247-2568 or via e-mail at jhoechst@ndia.org and refer to the Insensitive Munitions and Energetic Materials Conference.

TUCSON AREA: THINGS TO DO

For more information on the Tucson area, things to do and possible spouse outings, visit http://www.visittucson.org/

EVENT #9550 ► NDIA REGISTRATION FORM

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION ► 2111 WILSON BOULEVARD, SUITE 400 ► ARLINGTON, VA 22201-3061 (703) 522-1820 ► (703) 522-1885 FAX ► WWW.NDIA.ORG

INSENSITIVE MUNITIONS AND ENERGETIC MATERIALS > LOEWS VENTANA CANYON RESORT TUCSON, AZ ► MAY 11-14, 2009



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- Educator/Academia
- Professional Services
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- > Other _

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- Legislator/Legislative Aide
- General/Admiral
- Colonel/Navy Captain
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QUESTIONS, CONTACT:

JENNIFER HOECHST, **MEETING PLANNER**

PHONE: (703) 247-2568

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2009 INSENSITIVE MUNITIONS AND ENERGETIC MATERIALS TECHNOLOGY SYMPOSIUM

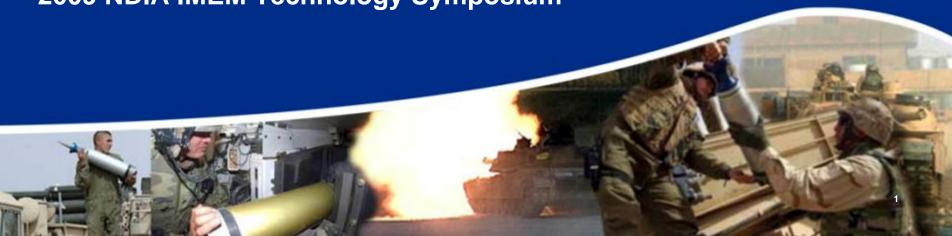
LOWER COST SOLUTIONS FOR 21ST CENTURY IM/EM REQUIREMENTS

LOEWS VENTANA CANYON RESORT > TUCSON, AZ

GENERAL DYNAMICS Ordnance and Tactical Systems

120MM IMHE-T® AN IM SOLUTION FOR CURRENT AND FUTURE OPERATING ENVIRONMENTS

Presented By: Jason Gaines, Systems Engineer 2009 NDIA IMEM Technology Symposium



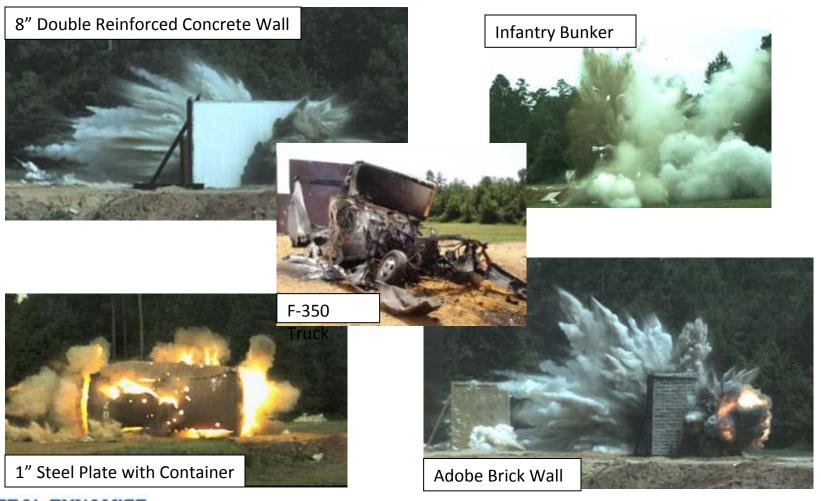
120mm IMHE-T® Program Background

- GD-OTS and Nammo teamed together in 2002 to develop a low cost, IM compliant high explosive round of tank ammunition.
- IMHE-T® has Multi-Purpose (MP) capability against a target set that includes bunkers, reinforced concrete walls, light armor and personnel.
- Currently in Qualification for Norwegian Ministry of Defense.
- FMS program for Government of Egypt to begin Q3 2009





120mm IMHE-T® MOUT Target Performance





Insensitive Munitions (IM) Objectives

IM Test	Test Spec.	Passing Criteria
Slow Cook Off (FCO)	STANAG 4382	TYPE V
Fast Cook Off (SCO)	STANAG 4240	TYPE V
Bullet Impact	STANAG 4241	TYPE V
Sympathetic Reaction	STANAG 4396	TYPE III or better
Shaped Charge Jet Impact	STANAG 4526	TYPE III or better

Reaction Descriptions

Type	Description		
I	Detonation		
Ш	Partial Detonation		
III	Explosion		
IV	Deflagration		
V	Non-Propulsive Burning		

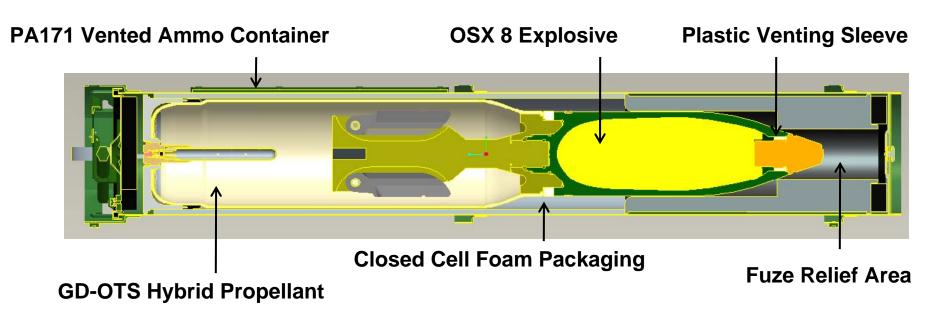




Systems Approach to IM Design

Key IM Design Concepts

- 1. Energetics must have good IM properties such as insensitivity to external shock and thermal stimuli.
- 2. Must eliminate all pressure build up caused by energetic confinement.







OSX-8 High Explosive

- □ Low Cost IM Explosive
- □ DNAN Based Explosive
 - Incorporates HMX and NTO
 - Comp B performance
 - Low Shock Sensitivity
 - Excellent IM Properties
- Produced by BAE Holston using existing equipment/facilities
- Utilizes existing melt pour LAP facilities
- □ Interim Qualification Status





HYBRID Propellant

State-of-the-art in Propellant Technology for Small, Medium and Large Caliber Ammunition

Excellent IM Characteristics
Low sensitivity to external
shock or thermal stimuli

All Qualification Testing Complete

Illustration of a propellant grain cross section

Deterrent Layer - applied to tailor the burn rate for specific applications to optimize ballistic efficiency





IM Test Series IAW MIL-STD 2105 C

(Conducted in July 2007 – Feb 2009 by GD-OTS and Nammo)

IM test:	Req. Type
 Slow Cook-off 	5
Fast Cook-off	5
 Bullet Impact (HE and Pro.) 	5
 Shaped Charge Jet (HE and Pro.) 	Pass (3-5)
 Sympathetic detonation 	Pass (3-5)

Environmental Test Sequence:

- 28 day T & H
- Vibration
- 4 day T & H
- 12 meter drop test Safe to dispose



Slow Cook Off Test Setup, Aug '07





Packaged Munition placed in an insulated oven.

Temperature is ramped to 50°C over a period of 1 hour and stabilized

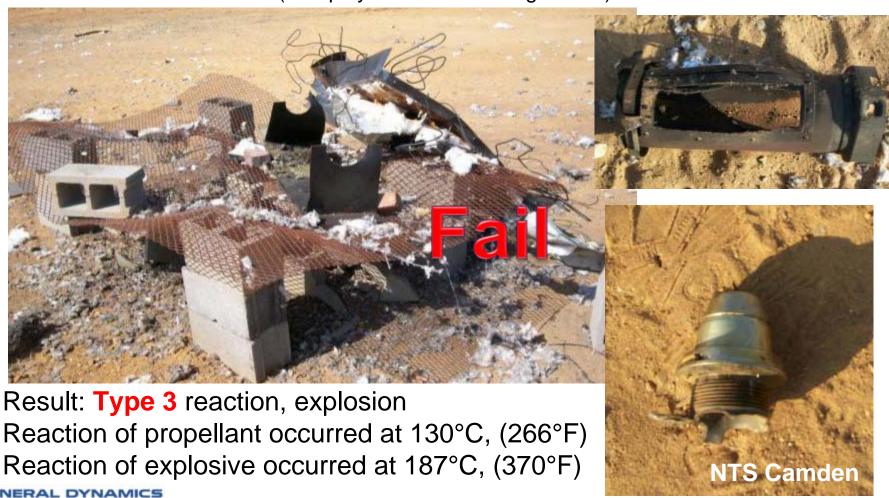
Temperature is then ramped at a rate of 3.3°C per hour until reaction occurs





Slow Cook Off Test 1 Results, Aug '07

(with polycarbonate venting sleeve)





Slow Cook Off Test 2 Results, Dec '07

(with HDPE venting sleeve)



Result: Type 5 reaction, burning only Reaction of propellant occurred at 130°C, (266°F) Reaction of explosive occurred at 186°C, (367°F)





Fast Cook Off Test 1 Setup, Aug 07

(with Polycarbonate venting sleeve)

Packaged munition placed above 1000 gallons of Kerosene.





Fast Cook-off Test 1 Result, Aug '07

(with Polycarbonate venting sleeve)



Result: Type 4 Reaction
Propulsive reaction of warhead

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NTS Camden

Fast Cook Off Re-Test Setup, July '08

(with HDPE venting sleeve)

Filled warhead w/ inert fuze, placed above 1000 gallons of Kerosene





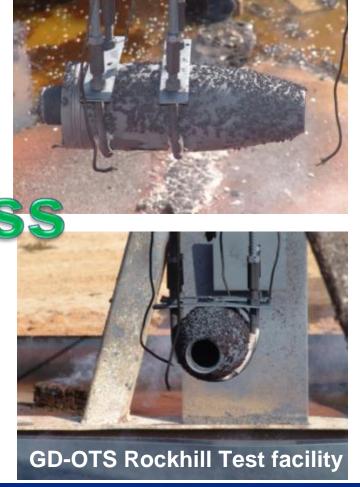


Fast Cook-off Test Results, July '08

(with HDPE venting sleeve)



Result: Type 5 Reaction at 22 min.



Bullet Impact Test Setup, Aug '07

Conducted two (2) BI tests

Test 1 – Three (3) round burst of 12.7 mm AP rounds fired at center of the warhead.

Test 2 – Three (3) round burst of 12.7 mm AP rounds fired at center of the propellant bed.



Ordnance and Tactical Systems



Bullet Impact Test Results, Aug '07

Shot to the warhead Type 5

Shot to the *propellant*Type 5



Sympathetic Detonation Test Setup, Feb '09





Ordnance and Tactical Systems



Sympathetic Detonation Test Results, Feb '09





Shaped Charge Jet Test 1 Setup, Aug '07

Conducted two (2) SCJ tests

Test 1 - 50 mm Rockeye SCJ fired directly into warhead

Test 2 – 50 mm Rockeye SCJ fired directly into propellant bed.





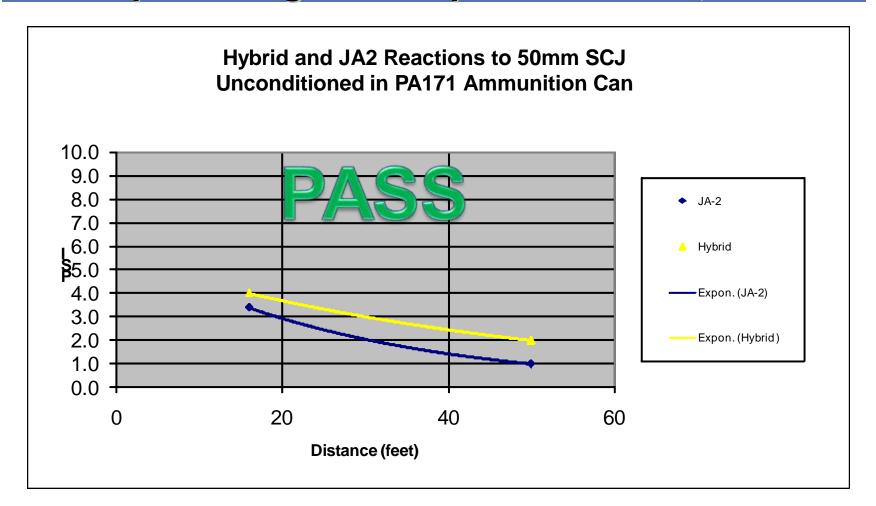
Shaped Charge Jet Test 1 Results, Aug '07



GENERAL DYNAMICS Ordnance and Tactical Systems



Shaped Charge Jet Propellant Results, Jan '08







Environmental Test Sequence

28-Day Temperature and Humidity Test

Hot Cycle: +63°C at 95% RH Cold Cycle: -40°C

Three (3) Rounds in Packaged Configuration

Pass

Remove and Inspect

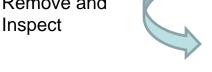


Transportation Vibration Test Sequence

Two-Wheeled Trailer Vibration **Shipboard Vibration Exploratory Vibration** Variable Frequency **Endurance**

Pass

Remove and



4-Day Temperature and Humidity

Test

Hot Cycle: +63°C at 95% RH Cold Cycle: -40°C

Pass

Remove and Inspect

12 Meter Drop Test

Round 1: Vertical (nose down) Round 2: Vertical (base down) Round 3: Horizontal

Pass

GENERAL DYNAMICS Ordnance and Tactical Systems



IMHE-T IM Test Summary

IM Test	Test Spec.	Passing Criteria	Results
Slow Cook Off (FCO)	STANAG 4382	TYPE V	Type V
Fast Cook Off (SCO)	STANAG 4240	TYPE V	Type V
Bullet Impact	STANAG 4241	TYPE V	Type V
Sympathetic Reaction	STANAG 4396	TYPE III or better	Pass
SCJ Impact	STANAG 4526	TYPE III or better	Pass

The 120mm IMHE-T has successfully completed all customer IM requirements





Path Forward and Conclusions

- The 120mm IMHE-T® will be considered fully IM compliant without waivers or deviations upon successful completion of testing this summer.
- Successfully meets all ballistic and lethality requirements without compromising crew survivability.
- Currently in Leopard II Qualification for Norwegian Ministry of Defense June Completion
- FMS Case for Abrams set to begin Q3 2009.







GENERAL DYNAMICS
Ordnance and Tactical Systems







REPLACEMENT OF OCTOL WITH IM EXPLOSIVE IN SMAW HEAA WARHEAD

C. W. Gonzalez, N. C. Johnson, K. W. Reed, L. A. Kowalczyk, W. L. Myers, V. L. Beam, and V. A. Fields

Indian Head Division, Naval Surface Warfare Center Indian Head, MD



Presentation Outline

- Objectives
- Approach
- System Description
- Explosive Selection
- Qualification and Performance Tests
- Summary
- Acknowledgements



Objectives

- Replace SMAW HEAA warhead fill (Octol) with explosive of comparable performance and improved IM characteristics
 - Sponsor directive: only system change will be explosive fill
- Meet current HEAA penetration requirements
- Qualify SMAW HEAA with IM warhead fill (SMAW HEAA-IM Warhead)



Approach

- Phase I: Explosive Selection
 - Explosive Selection Committee
 - IM and Performance Testing in SMAW HEAA Warhead
 - Downselection to Final Explosive Fill

 Phase II: Qualification and Performance Testing SMAW HEAA-IM Warhead





4 of 28

SMAW HEAA System Description

- Shoulder-launched Multi-purpose Assault Weapon High Explosive Anti-Armor
- DODIC HX06
- Effective against medium armor
- SMAW HEAA consists of:
 - MK 153 MOD 0 Launcher
 - SMAW HEAA Encased Assault Rocket (EAR)
- SMAW HEAA Rocket consists of:
 - Rocket motor
 - Impact fuze
 - Shaped charge, high explosive warhead





SMAW HEAA Encased Assault Rocket





Selection of IM Explosive Candidates





Explosives Assessment

- Explosive Output
- IM Survivability
- Safety & Reliability
- Producibility / Life Cycle Costs





Explosive Candidates

- PBXN-9
 - Used in Navy & Army shaped charge ordnance
 - Good IM in FCO/SCO/BI
 - Bad IM in FI
- PBXN-11
 - Better performance than PBXN-9
 - Good IM in FCO/SCO
 - Bad IM in BI/FI
- PBXW-114
 - Equivalent performance to PBXN-110
 - Good IM in FCO/SCO/BI
 - Potential for significant improvement in FI



Explosive Properties

Explosive	Composition	Manufacture Method	Density, g/cc	FCO/SCO/BI
DDVAL 0			4.70	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
PBXN-9	HMX/binder	pressed	1.73	V/V/V
PBXN-11	HMX/binder	pressed	1.80	V/V/IV
PBXW-114	HMX/Al/binder	cast	1.71	V/V/V
		melt (sedimentation)		
Octol	HMX/TNT	cast	1.82	I/I/V



Phase I. IM and Performance Tests





Phase I Testing

Slow Cook-Off

- 2 rockets with live warhead assemblies and inert rocket motor and fuze, of each explosive fill plus Octol baseline
- Tests performed at Dahlgren Division, NSWC

Fragmentation Impact

- 2 rockets with live warhead assemblies and inert rocket motor and fuze, of each explosive fill plus Octol baseline
- Tests performed at Dahlgren Division, NSWC

Penetration

- 3 warheads of each explosive fill (2 for PBXN-11) plus Octol baseline
- Tests performed at Dahlgren Division, NSWC

Flash X-ray

- 2 warheads of PBXN-9 and PBXW-114 fills plus Octol baseline
- No PBXN-11 loaded warheads available
- Tests performed at ARL, Aberdeen, MD



PBXN-11 Loading

- Problems encountered loading PBXN-11 charges
- PBXN-11 tended to adhere to case wall when pressed under conditions used for PBXN-9 charges and caused case deformation
- PBXN-11 charges for tests were pressed as free-standing billets, slipped into warhead case, and then pressed lightly
- Loading process improvement required if PBXN-11 selected

Summary of Phase I Results

Explosive	L)ensity I	Current	Penetration	IM Reactions			
		Processibility		sco	Frag Impact (T1 8300 ft/sec, T2 6000 ft/sec)		
PBXN-9	1.744	Yes	passed	(IV)** (2) Deflagration	l (2) Detonation		
	1.744						
	1.750						
PBXN-11	1.769 *	No	passed	(V)** (2) Burn	I (2) Detonation		
	1.803						
PBXW-114	~1.71	Yes	failed	(IV)** (2) Deflagration	I (1) Detonation	(IV)** (1) Deflagration	
Octol	1.80-1.85	N/A	baseline	I (2) Detonation	I (2) Detonation		
	* 98% TMD is 1.793 gm/cc. 1.769 is 96.7% TMD						
**Not officially scored; engineering judgement of test results							



IM Explosive Selection

- PBXN-9 Selected
- Based on
 - Performed well in penetration tests
 - IM characteristics
 - Fielded as main charge in other shaped charge warheads
 - Drop in solution
- Place barrier tape between PBXN-5 booster and PBXN-9 explosive
- Informally refer to SMAW HEAA system with PBXN-9 warhead fill as "SMAW HEAA-IM Warhead"



Phase II. Qualification and Performance Tests for SMAW HEAA-IM Warhead





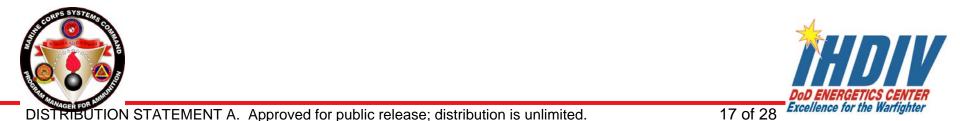
Qualification and Performance Tests

- Objectives
 - Ensure that SMAW HEAA-IM Warhead meets IM and Hazard Classification (HC) requirements
 - Obtain Final (Type) Qualification of the SMAW HEAA-IM Warhead
 - Verify that replacement of warhead fill has not caused degradation of system performance



Phase II Tests

- Test Items
 - Built by Nammo Talley, Inc.
 - Warheads loaded by IHDIV, NSWC
 - Liners are Government Furnished Material (GFM)
 - Mk 259 Fuzes are GFM
- Testing will be conducted by National Technical Systems (NTS), Camden, Arkansas during March – June 2009



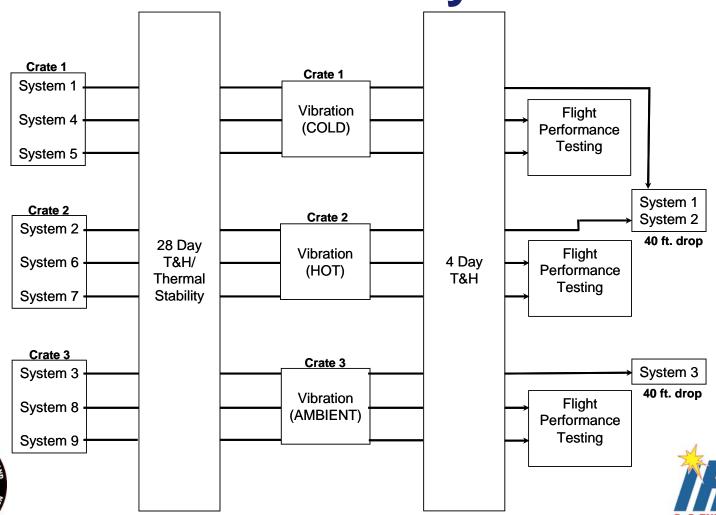
Qualification Tests

Tests harmonized for IM and HC Purposes, but include only a limited subset of HC and FTQ tests, since this effort is only changing the warhead explosive fill and not safety features of the system

- Basic Safety Tests w/ Thermal Stability
- Sympathetic Detonation (Stack Test)
- Fast Cook-Off
- Slow Cook-Off
- Bullet Impact
- Fragment Impact



Basic Safety Tests w/ Thermal Stability

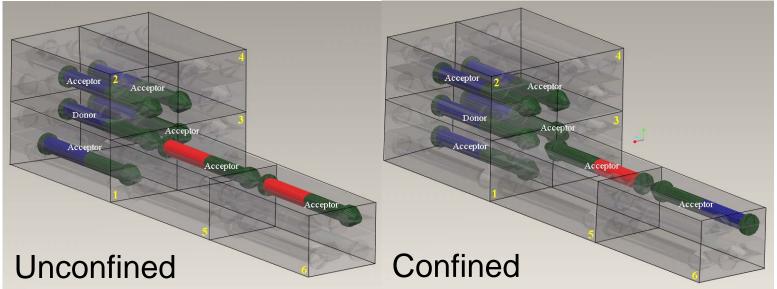


DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Excellence for the Warfighter

Sympathetic Detonation

- IAW MIL-STD-2105C and STANAG 4396
- Both unconfined and confined stack tests
- Variously configured rounds in each test
- Expected results: Passing reaction



Fast Cook Off

- IAW MIL-STD-2105C, STANAG 4240, & NAVSEAINST 8020. B
- Two FCO Tests
 - (1) test with 6 All-Up Rounds in shipping container
 - Expected result: Type I Detonation
 - (1) test with single, bare EAR with live warhead assembly and spotting cartridge, and inert rocket motor and fuze
 - Expected result: Type V Burn



Slow Cook Off

- IAW MIL-STD-2105C and STANAG 4382
- (2) tests conducted on bare EARs containing live warhead assemblies and inert rocket motors, fuzes and spotting cartridges
- Expected result: Type IV Deflagration at warhead level



Bullet Impact

- IAW MIL-STD-2105C and STANAG 4241
- (2) tests on bare EARs containing live warhead assemblies and inert rocket motors, fuzes, and spotting cartridges
- Expected result: Type V Burn at warhead level

Fragment Impact

- IAW MIL-STD-2105C and STANAG 4496
- (2) tests on bare EARs with live warhead assemblies and inert rocket motors, fuzes, and spotting cartridges
- Expected result: Type I Detonation



Performance Testing

- Flight performance testing on All-Up Rounds at hot, cold, and ambient temperatures
- Static penetration testing on warhead-only assemblies against RHA
- Accelerated aging and vibration profiling sequence, followed by static penetration, on warhead-only assemblies
- Flight performance and penetration testing conducted IAW Weapon Specification

Summary

- PBXN-9 selected as IM explosive for SMAW HEAA warhead
- Qualification test plan received concurrence from WSESRB and Hazard Classification offices
- Warheads have been loaded
- Test items have been built
- Qualification and performance testing is underway





Acknowledgments

- Sponsor: Marine Corps Systems Command Program Manager for Ammunition (PM Ammo)
 - Program Manager: Richard Dooley
 - Project Engineer: Richard Hardy
 - Technical Advisor: Tim Portner, Dahlgren Division, NSWC
- Test item build: Nammo Talley, Inc.
 - Project Manager: Will Betush
 - Project Engineer: Glade Hansen



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- Indian Head Division, Naval Surface Warfare Center
- Phone: 301-744-2575
- Email: <u>nancy.c.johnson1@navy.mil</u>





2009 Insensitive Munitions & Energetic Materials Technology Conference

Linear Demolition Charge Insensitive Munition (IM) Program (# 8238) May 11-14, 2009 Loews Ventana Canyon Resort, Tucson AZ







Robert S Hutcheson Jr.*
Code E312F, Bldg 302-114

Brian Amato Zaeemuddin Husain

Christopher Gonzalez

Ray Gamache

NSWC, Indian Head Division and

Greg Little

Tom Swierk

of NSWC, Dahlgren Division



Joint Service Investment

- Technology Transition Agreement (TTA) established in 2005 as collaborative program between Office of Naval Research and PM-Ammo to improve the level of compliance for Mine Clearance System (MCS) to IM requirements and to improve the functional reliability of system
 - Jointly Funded 2005 And 2006
- Current Funding PM-Ammo only



Program Leads for Tasking

 Organization: Program Manager for Ammunition Marine Corps Systems Command (MCSC)

Program Manager: Mr. Jerry Mazza, MCSC

Assistant Program Manager: Capt F. Matt Williams

IM Technical Support: Mr. Scottie Allred
Mr. Gregory DuChane

Organization: PM Engineer System for ABV
 Marine Corps Systems
 Command (MCSC)

Program Manager: Mr. Joseph Augustine

Project Officer: Mr. Joseph Burns

Organization: Naval Surface Warfare Center,
Dahlgren Division

Project Manager: Mr. Thomas Swierk

Shielding: Mr. Greg Little

Organization: Naval Surface Warfare Center,
Indian Head Division

Project Manager: Ms. Nancy Johnson

Energetic Materials: Mr. Robert Hutcheson

Rocket Motor: Mr. Leandro Garcia

Safety: Ms. Vonderlear Fields

• Configuration Manager: Ms. Terrie Green



Current and Expected IM Response

M58 and M59 Linear Demolition Charge (LDC) IM Test Reactions										
SYSTEM	FCO SCO BI FI SD SCJ									
LDC										
M58A4/ M59A1 ¹	V	V	1	1	1	(I) ²				
M58A4E1/ XM651	V	V	(V) ³	V ³	I	(I) ²				
M1134A4 (Fuze)	V	(V)	V	V	(Pass)	(Unknown) ²				

- () By analysis
- 1. M58 and M59 were evaluated by OHEB 22 May 2002 in accordance with "Hazard Assessment Tests for Non-Nuclear Munitions," MIL-STD-2105B. (NAWCWD TM 8380, Katsumoto K. T., M913 and ML25 Linear Demolition Charge Insensitive Munitions Tests, August 2002)
- 2. SCJ for M58/M59 is based on FI. The fuze is not likely to be hit by SCJ and therefore is likely to be a pass since it is not connected to anything else in the shipping container until launch
- 3. IMRB scored the test results for the all-up improved M58 as a NO Test due to not meeting the requirements of MIL-STD-2105C, but did score the sub-scale tests without detonating cord as Type V reaction. FI for M58 with the new detonating cord, relay cups and shield was a Type V reaction. (NSWCDD ltr 8010.1 Ser G702/005 of 13 Oct 2007, IMRB Meeting on the M58 Linear Demolition Charge and Mk 22 Mod 4 rocket motor)
- Nomenclature for the IM version of the M59A1 has been receive as the XM651



ENERGETIC MATERIAL INFORMATION

New Energetic Materials IM Mine Clearance System (MCS)

Component	Explosive	Weight									
Explo	Explosive Components Main Charge LDC (M58A4/ M59A1)										
Pellet	Composition C-4 Class III	1750 Nominal Ibs									
Detonating Cord	PETN	12.24 lbs									
Relay Cups	PETN	6.24 g.									
Explos	Explosive Components Main Charge LDC (M58A4E1/ XM561)										
Pellet	Composition C-4 Class III	1750 Nominal lbs									
Detonating Cord	PBXN-8	16.35 lbs.									
Relay Cups	Composition A-5	1.56 g									
Explosive Cor	Explosive Components Rocket Motor (Mk 22 Mod 3/Mod 4 and EX 22 Mod 5)										
Propellant	N-5, Double Based	42.00 lbs.									
Electrical Initiator	Bridgew ire Composition	65 mg									
	Initiator	220 mg									
lgniter	lgniter Charge	48 g									
Explosive Components Fuze (M1134A4)											
Bellow s	Ignition Charge	120 mg									
Dellow 3	Gas Producer	70 mg									
	Ignition Charge	280 mg									
Detonator	Intermediary Charge	15 mg									
	Output Charge	15.2 mg									
Lead (2)	Composition A-5	1284 mg									

Linear Demolition Charge Background

- USMC requirement for a reliable, safe, and effective system for clearing mines.
- Provides a "close-in" breaching capability for maneuver forces.
- Utilizes 50+ year-old technology
- Since initial fielding there has been little done to form, fit or function.
- Procurement of Ammunition, Navy, and Marine Corps (PANMC) funds are provided to procure components which make up the Mine Clearance System.



Linear Demolition Charge Description

- Mine-clearing system used to clear path for tanks, vehicles and personnel. System clears a path 350 feet long by 46 feet wide path.
- Rocket Motor tows Line Charge from container over obstacles or minefields.
- Deployment platforms
 - Mk 1 Mod 0 Up to three M59 line charges deployed from inside an Amphibious Assault Vehicle (AAV), uses the Mk 154 Hydraulic Launcher.
 - Mk 2 Mod 0 Up to two M58 line charges deployed from the Assault Breaching Vehicle (ABV) or one M58 line charge deployed from Trailer, uses the Mk 155 Hydraulic Launcher.
- Effective against single-impulse, pressure-type, nonblast hardened anti-tank mines and mechanically actuated anti-personnel mines.



MK 1: AAV Launch of M59



MK 2: M58 Launched from trailer



/IK 2: ABV Launch of M58



Linear Demolition Charge Description

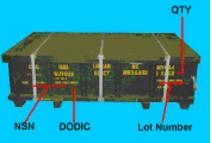
- Mk 1 Mod 0 MCS
 - M59 line charge in steel/aluminum shipping/storage container
 - Line charge unpacked length 555 ft
 - Explosive section 350 ft long
 - 700 Composition C-4 Blocks plus Detonating Cord
 - Total Explosive Weight 1750 lb
 - M1134A4 fuze
 - MK 22 Mod 4 rocket motor
- Mk 2 Mod 0 MCS
 - M58 line charge in steel shipping/storage container
 - M1134A4 fuze
 - MK 22 Mod 4 rocket motor

Note: M58 and M59 line charges are identical; containers and packing configuration are different



M59





Linear Demolition Charge (LDC)

- LDC Improvements
 - Completed DVT 26 Sept 07
 - 2 Full scale deployments
 - Multiple Partial Length Air Gun Deployments
 - BI and FI test of M58A4 modified w/Comp A-5 Relay Cup and PBXN-8 Detonation Cords
 - Completed CDR 17 April 08
 - Preparing TDP to procure qualification units
 - Received guidance from PM Ammo on 25 Sept 08 to incorporate a Line Cutter into the M58 LDC and container



Linear Demolition Charge (LDC)

- Accomplishments for M58/M59
 - Completed detonating cord testing December 2007
 - Down selected PBXN-8 to replace PETN loaded detonating cord
 - Down selected Comp A-5 to replace PETN loaded relay cups
 - Tested and down-selected shielding
 - Completed design for over-braid configuration for LDC
 - DVT M58 full system w/new detonating cord/relay cups/shielding
 - Shielding used Aluminum plate and ¾" ceramic balls
 - Shielding permitted C-4 to pass BI and FI in sub-scale tests
 - Shielding permitted M58 to pass FI and similar results for BI



DETONATING CORD

Testing Requirements

			Results									
Test method	Objective	PETN (POMINS)		PBXN-8 (APOBS)		PETN (M58)		PBXN-8 (A1)		PBXN-8 (A2)		References
		Amb	-65°F	Amb	-65°F	Amb	-65°F	Amb	-65°F	Amb	-65°F	
SCO	To Compare the reaction level to MIL- STD-2105C	- N/A		Burn Detonation		Burn		Burn		NSWC TR 90- 170 For APOBS		
FCO	To Compare the reaction level to MIL- STD-2105C	N/A Burn		ırn	Burn		Burn		Burn		NSWC TR 90- 170 For APOBS	
Bullet	To Compare the reaction level to MIL-STD-2105C	1/50 detonation		50/50	burns	1/1 detonation		5/5 Burn		5/5 Burn		NSWC TR 90- 170 For APOBS
Impact	To Compare Relay Cup reactions	charre	let, 7 d, 17 no ction	no reaction		1/1 det	onation	1/4 detonation of relay cup with no transfer to Detonating Cord		3/3 Burn		NSWC TR 90- 170 For APOBS



Down Selected Detonating Cord

- Based on testing to date PBXN-8 has been down selected for the detonating cord with Composition A-5 Relay Cups
- WS 35291 generated to cover requirements



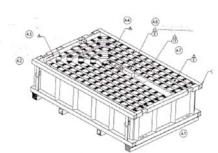
Main Charge for LDC

- Current M58/M59 System uses Composition C-4 for Main Charge
 - This material is suspected as the other major causes of System Failure
 - Looked at PBXN-9, PBXN-10, PBXIH-18 and other materials developed for IM improvements
 - Main Charge Program
 - Down Selected Main Charges
 - IM Response for these materials
 - FCO Variable Confinement Cook-Off Test (VCCT) Test Results
 - SCO VCCT Test Results
 - Fragment Impact Test Results
 - Transfer Testing
 - Results for the above reported at 2006 IM&EM Conference in a Poster Presentation
 - IM response in Hybrid Test
 - IM response in all-up system tests
 - All-up flight tests



HYBRID IM Testing

- Three IM Tests were performed
 - Hybrid Bullet Impact (BI)
 - 1 test without shielding 250 lbs of C-4 and remainder inert = Hybrid System B
 - 1 test with shielding 492.5 lbs of C-4 and remainder inert = Hybrid System A
 - Hybrid Fragment Impact (FI)
 - 1 test with shielding 492.5 lbs of C-4 and remainder inert = Hybrid System A
- Perform Hybrid Tests without Detonating Cord on System
 - To determine if C-4 will survive if we replace the detonating Cord
 - 3 Modified M58A4 Line Charges
 - HF and Inert Pellets
 - 2 Hybrid System A
 - 1 Hybrid System B
 - All PETN Detonating cord & Relay Cups Removed
 - In Packing/Shipping Configuration
 - M58 (I x w x h) (82.15" x 53.75" x 24")
 - HE & Inert Charges Identifiable By Color and Tape Indicator



Typical View of MICLIC HYBRID SYSTEM A &



Hybrid M58 Shipping Containers and Selected IM Performance Tests **Bullet Impact Test on Hybrid System B Without Shielding Point of Impact (AFT End Of Container)**





			S/N: HB-00	01			
Temperature		50°F		lumidity	55%		
Barometric Pressure		9.86 inHg	Wind Spe	ed/Direction	5.0 MPH / South		
Bullet Type	(3) .50 calibe	r M-2 Armor	Piercing				
A STATE OF THE PARTY OF THE PAR		60"x2" thick	Witness P	late Damage	Destroyed		
Reaction Type		Type I	Aim Point		Center line of Test Unit		
Probe Number	Distance	PSI Delay Times		S			
1	40' 4.5"	No Date	a 1	to 2	94 ms		
2	50' 7"	No Data	2	to 3 1	05 ms		
3	501	No Data	a				
Bullet Velociti	ies (Ft/Sec)						
Gun 1	No Data						
Gun 2	No Data						
Gun 3	No Data						

Test Results: Pressure lines cut and velocity screens destroyed. The system detonated on impact with the second round. The third round never left the barrel.

Hybrid M58 Shipping Containers and Selected IM Performance Tests

Bullet Impact Test on Hybrid System B Without Shielding Point of Impact (AFT End Of Container)

IMRB's score Type I detonation reaction





Hybrid M58 Shipping Containers and Selected IM Performance Tests **Bullet Impact Test on Hybrid System B Without Shielding Point of Impact (AFT End Of Container)**





Shot #1 – Damaged Guns

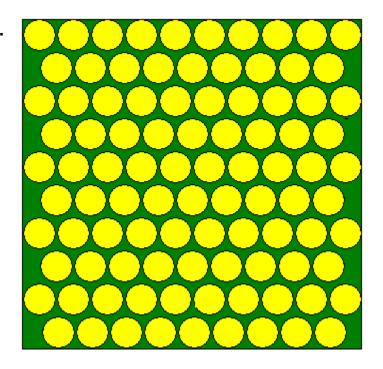
Instantaneous Detonation after 2nd Round before 3rd Round could be fired



Shot #1 – Collection of some of the Debris

Shielding For Bl and Fl Hybrid Tests

- Shielding was used on the second BI test
- Shielding was used on the FI test.
- All shielding panels were 10" wide & 14" long.
- Description:
 - 5/8" Ceramic Spheres Bound In A Polyurea Coating
 - Backed By 0.202" High Hard Steel were attached onto LDC Container Test Target Area With Velcro
 - Applied To The Container On Day Of Test
 - All Shielding Material Provided By NSWCDD (Dr. Ray Gamache/Greg Little)
 - Previously discussed in IM & EM 2006
 Poster # 3408





Hybrid M58 Shipping Containers and Selected IM Performance Tests Bullet Impact Test On Hybrid System A With Shielding Point Of Impact (Side Portion Of Container)

Procedure

- Bullet Impact Test was conducted in accordance with MIL-STD-2105C, paragraph 5.2.3
- Purpose of the test is to evaluate the response of each test item to the bullet impact test specified in MIL-STD-2105C, Paragraph 5.2.3

Unit Configuration

One containerized modified Hybrid A system

Test

- The System shall be impacted by three .50 caliber type M2 AP projectiles
 - Velocity of 850 \pm 60 m/s (2800 \pm 200 ft/s)
- the center of the live pellet area to ensure live pellets are above, below, around and behind the bullet impact points.
- This allows bullets to strike to the left and right of the aim point
- The fixture will support the container and restrain it from any undesired motion due to the bullet impacts.
- Pressure gauges were used to measure any resulting overpressure
- Fragmentation distances and weights were recorded

Criteria for Assessing Results

- The criteria for assessing the results of this test are found in paragraph 5.2.3.4 of MIL-STD-2105C
- The passing criterion of MIL-STD-2105C is no reaction more severe than Type V





IMRB scored Type V Burning Reaction



Hybrid M58 Shipping Containers and Selected IM Performance Tests
Fragment Impact Test on Hybrid System A With Shielding Point of Impact (Side Portion Of Container)

Procedure

- The purpose of the test is to evaluate the response of each test item to the Fragment Impact test specified in MIL-STD-2105C, Paragraph 5.2.4.
- The tests are being conducted to evaluate the response of the System to impacts from three fragments moving at 8300±300 ft/sec.

Unit Configuration

One containerized modified Hybrid A system

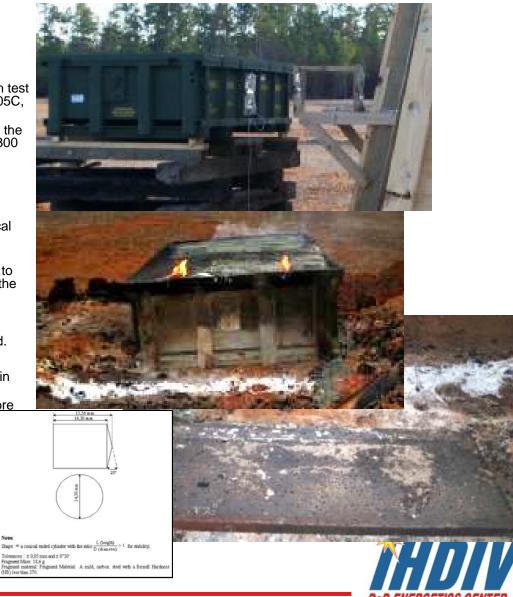
Test

- Each test item shall be impacted by 1 fragment size (conical ended cylinder weighing 18.6 grams)
- Velocity of the fragment 8300 ± 300 ft/s
- Fragments were aimed at the center of the live pellet area to ensure live pellets area above, below, around and behind the fragment impact point.
- Pressure gauges were used to measure any resulting overpressure
- Fragmentation distances and weights will also be recorded.

Criteria for Assessing Results

- The criteria for assessing the results of this test are found in paragraph 5.2.4.4 of MIL-STD-2105C
- The passing criterion of MIL-STD-2105C is no reaction more severe than Type V.

IMRB scored Type V Burning Reaction



Excellence for the Warfighter

Demonstration Validation Tests (DVT)





Optimizing Shielding Design

Ballistic testing recently completed to assess the response of various configurations to:

Minimize panel weight & evaluate low cost options

Typical Fragment Impact test results:

Panel front side (entry hole)



Panel backside (exit hole)



Recommended Shielding Configuration:

0.75 In. Ceramic Spheres

Polymer Adhesive Binder

0.25 in. Al Substrate Panel



Setup of the LDC for Bullet Impact



DOD ENERGETICS CENTER Excellence for the Warfighter

Camera view from Rocket Mountain of Bullet Impact

(1357) Smoke appears within minutes





(1400) Flames grow rapidly

(1403) Flames burstfrom the sides approx27 ft on the right and16 ft on the left





(1409) Flames begin to decrease through 1530



Post-test picture of the LDC Bullet Impact



IMRB scoring of NO TEST because test did not meet the test requirements. The IMRB did note that the reaction exhibited was consistent with Type V (Burning) standards.



Linear Demolition Charge Insensitive Munitions Fragment Impact Test Set-Up





Linear Demolition Charge Insensitive Munitions Fragment Impact Test Results









IMRB Scored FI Type V reaction



Summary of BI and FI

- Tasking was performed by NSWC Crane, Fallbrook Detachment
- The LDC Bullet Impact test was conducted on Dec. 13, 2006 at Hawthorne Army Depot (HWAD).
- The LDC FI test was conducted on 15 May 2007 at NAWS China Lake,
 Ca.
- For BI only 2 rounds were fired and they were 6 inches apart
- Fragment velocity was 8439 ft/sec
- Both the BI and FI tests of the M58 burned for 1 hr and 10 mins before flame out
- The LDC achieved the desired burning reaction from the BI and FI. The outcome had a type V like reaction (Burn).
- IMRB Scored All-up System BI No Test but Overall score a Burn
- IMRB Scored FI Type V reaction
- Confirmed IM performance objectives met
 - Improve BI from Detonation to Burning for M58
 - Improve FI from Detonation to Burning for M58



LDC IM IMPROVEMENT EFFORT

Full Scale Test Set-up for LDC





LDC IM IMPROVEMENT EFFORT

Results

- Testing culminated with deployment by a MK 22 Rocket and successful detonation train transfer on a full length hybrid Live-Inert LDC
- Detonating cord management concepts Sinusoidal (Current Design) –
 Proved successful New connectors design for overbraid LDC system
 - Rocket Motor End Connector finalized and validated
 - Fuze-End Connector experienced a few modifications throughout the project
 - Minimized the weight and size of initial design









Summary of LDC

- Based on the Main Charge Testing
 - Down Selected to C-4
 - Risk that Shielding Works Satisfactorily with the XM651 packaging needs to be Proven
 - Minimal Risk that Shielding will weigh too much to allow the system to be moved
 - All indications are that all handling systems will be able to handle the additional weight
- LDC Design is Acceptable
 - Passes BI with Burning reaction
 - Passes FI with Burning reaction
 - -SD and SCJ reaction will not change with design
 - Design Improves deployment method for LDC
 - Design maintains current capability for System Performance
 - Design maintains current system design margins
- Transition to Production



ACKNOWLEDGMENTS

- NSWCIHD Code R33 for their support in testing
- NTS for their support in the Hybrid BI and FI testing
- NSWCDD for their design of the Shielding used in the BI and FI tests
- NSWC Crane, Fallbrook Detachment for their support in Detail Development testing for all-up IM results in support of the TTA
- The support of the LDC Bullet Impact test by the Marine Corps Programs Division at Hawthorne Army Depot (HWAD).
- The support of LDC FI test at NAWS China Lake, Ca by the Ordnance Test and Evaluation Division.



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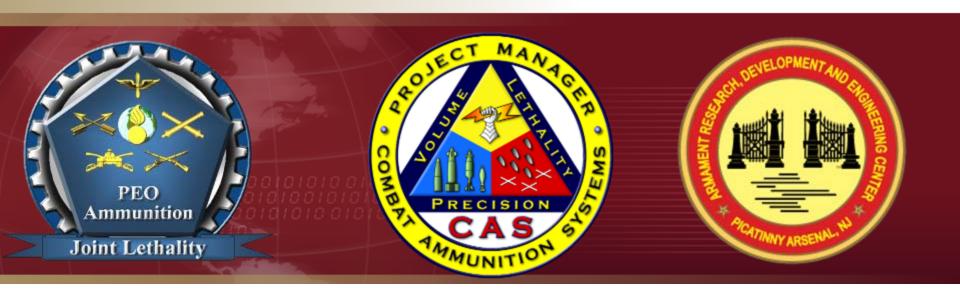
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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Common Low-cost Explosive Insensitive Munitions Program Phase 2: Explosive Replacement for Comp B

2009 Insensitive Munitions and Energetic Materials Technology Symposium

May 12, 2009

Philip Samuels

PM-CAS/US Army ARDEC

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DoD / Industry Participants



























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Background: Explosive Fills for PM-CAS Items



- **Baseline Explosive Fills**
 - TNT (Melt-pour)
 - Baseline for all 105/155mm Artillery 7 Projectiles
 - Comp-B (Melt-pour)
 - Baseline for all 60/81/120mm Mortar 6 Cartridges
 - Also allowed for Artillery's 105mm M1 and 155mm M107
- Efforts Prior to FY07 for IM Explosive Fills
 - 60mm Mortar
 - PAX-21 (Melt-pour) --- Type-Classified & Fielded
 - 81mm Mortar
 - T.B.D. --- leveraging 60mm & 120mm Mortar efforts
 - 120mm Mortar
 - HBU-88B (Cast-cure) --- Type-Classified
 - 105mm Artillery
 - T.B.D. --- no active program
 - 155mm Artillery
 - PAX-196 (Melt-pour)

Driven to IM Solution



Success of Phase I CLIMEX Program



- IMX-101 passed all Engineering IM Tests in the 155mm M795 Artillery Projectile
 - Met TNT lethality in M795
- IMX-101 was loaded in the 120mm M934A1 Mortar for IM and Lethality testing as part of the Common Fill evaluation
 - Performance tests proved that IMX-101 does not have enough energy to compete with Comp B in the 120mm Mortar



Common Low-cost IM Explosive Program



- New IM Explosive for Artillery and Mortar applications that are:
 - Effective
 - Maintain Lethality with minimal or no degradation
 - Less Sensitive
 - If not fully compliant, must show improvement over Baseline explosive
 - Affordable
 - Artillery Cost Drivers = Steel Body Material & Explosive Fill
 - Mortar Cost Drivers = Steel Body Material, Fuze & Propelling Charges
 - Producible within the National Technology and Industrial Base (NTIB)
 - Infrastructure
 - Raw Ingredients
 - Explosive formulation
 - Projectile Load, Assemble & Pack (LAP)
 - Other Considerations
 - Intellectual Property Rights
 - Demilitarization
 - Environmental



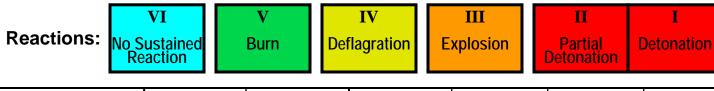
Primary Objective is to provide a Common IM Fill -- or --

one common TNT replacement (Artillery)...
..and one common Comp-B replacement (Mortars)



IM Test Results Mortar Baseline



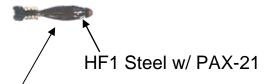


IM Test:	FCO	SCO	BI	FI	SD	SCJI	
Passing Criteria	V	V	V	V	III	III	
60mm (Comp-B/PAX-21)	Ⅱ V **	III II**	V	III	(I)*	(I)*	
81mm (Comp-B)	(II)*	(II)*	(III)*	(III)*	(I)*	(I)*	<- IPT Score
120mm (Comp-B)	II	I	I	I	(I)*	(I)*	

** with PAX-21 and Intumescent Coating

()* Assessment -- not tested

60mm



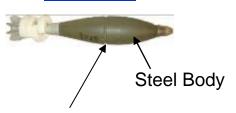
0.8 lb Explosive Fill [Comp-B: free] [PAX-21: ~\$15/lb]

<u>81mm</u>



2.0 lb Explosive Fill [Comp-B: free]

120mm



6.6 lb Explosive Fill [Comp-B: free]

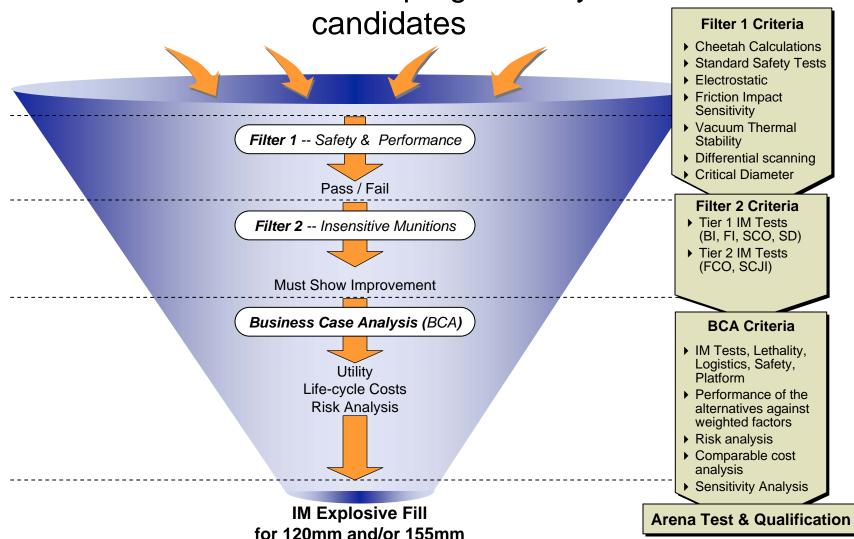
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Common Low-cost IM Explosive Program



"Funnel" framework to progressively screen



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



IM Formulations



• Sources:

- Historical / Government / Industry / Foreign
- QFD conducted by ARDEC
- PEO-AMMO IM Thrust Programs
- Navy and Air Force Explosives
- Industry efforts
- Phase I CLIMEX Program



Candidate Explosive Fills

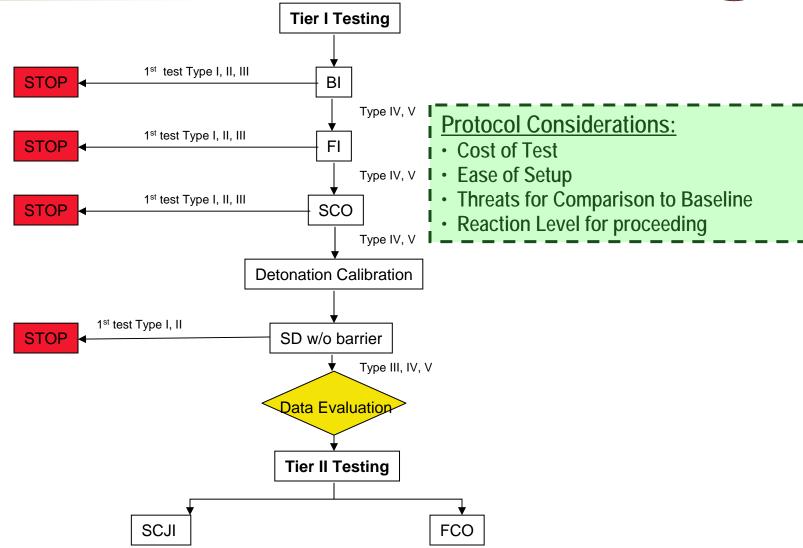


- Melt-pour
 - Traditional Ingredients
 - RDX
 - HMX
 - Less Sensitive Explosive Filler
 - NTO
 - NQ
 - Less Sensitive Energetic binder
 - DNAN
 - Nitrate Salts
 - Reduced Nitramines (Aluminized)
- Cast-cure
 - Inert binder
 - RDX
 - IRDX
 - Rounded RDX
- Press-fill
 - Inert binder with RDX (Redesign of metal parts Not Evaluated)



IM Test Matrix







Test Configuration



- IM Test Configuration for Comp-B Replacement (Mortars)
 - 120mm established as test vehicle
 - M934A1 Mortar Round with Standard Steel
 - No container for FI, BI, SCO
 - M734A1 MOFM Live Fuze
 - Reduced-thread Steel Fuze Adapter
 - PBXW-14 Booster Pellet to initiate IM fills
 - Replace CH6 Booster Pellet with PBXW-14 (if necessary)
 - Palletization configuration for SD
 - 2 rounds per PA154 Metal Container
 - One Round Up, One Round Down in Fiber Tubes
 - Wood (6 x 8)





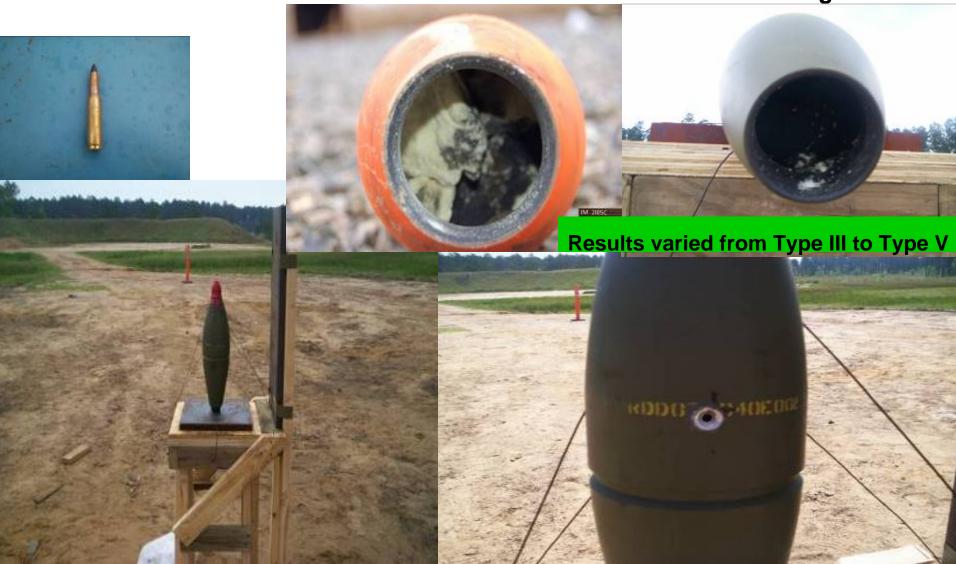




Bullet Impact Test



MIL-STD-2105C / 7.62mm AP Bullet / Witness Plate & Pressure Gage





Fragment Impact Test



MIL-STD-2105C / 6,000 ft/s Fragment / Witness Plate & Pressure Gage





Slow Cook-off Test



MIL-STD-2105C / 50F/hr / Precondition 145F / Witness Plate & Pressure Gage













Sympathetic Detonation Test



MIL-STD-2105C, PA154 Configuration, Witness Plate & Pressure Gages

PA154 w/o Barrier







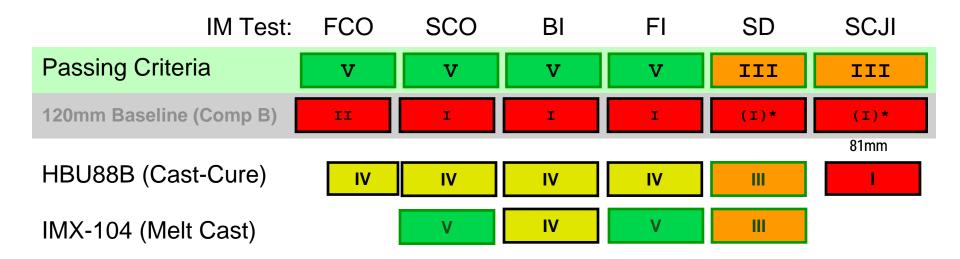


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IM Test Results





Engineering IM Tests in the M934A1
 120mm Mortar with IMX-104 show vast improvement over baseline Comp B



Fragmentation Analysis



ARL Water Pit Test

- Static detonation of M934A1 Mortars loaded with IM formulations and Comp B Baseline
- Soft Recovery of Fragments
- Fragmentation Analysis







Summary



- IMX-104 down-selected as best candidate based on IM, Lethality, Life Cycle Cost, and Production Readiness
- IMX-104 qualification:
 - 81mm M821A2 Mortar for FY11
 - -60mm & 120mm Mortars in FY12

PM-CAS Common Low-cost IM Explosive Programs resulted in two successful programs in attaining IM replacement formulations:
IMX-101 as the IM replacement formulation for TNT
IMX-104 as the IM replacement formulation for Comp B





Comparison between Polymerization Techniques for synthesis of Energetic Thermoplastic Elastomers

Khalifa Al-Kaabi and Albert Van Reenen

Department for Chemistry and Polymer Science, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa khalifa1@eim.ae

Presented at
2009 Insensitive Munitions & Energetic Materials Technology
Symposium
Tucson, AZ
May 11 - 14, 2009

Lower cost solutions for 21st Century IM/EM Requirements

Outlines of presentation

- Introduction
 - Insensitive munitions (IM)
 - GAP binder
- Polymerization methods
 - Redox polymerization techniques
 - Nitroxide-mediated process
 - Dithiocarbamate inferiter
 - Energetic thermoplastic polyurethane
- Conclusions
- Acknowledgments

Insensitive munitions (IM)

- High vulnerability of ammunitions and development of insensitive munitions (IM).
- Requirements for Insensitive munitions criteria
 - high performance, low sensitivity, environmental acceptance, and reasonable costs.
- Applied of polymeric materials (inert/energetic) in low sensitivity munitions (binders/plasticizers).

Redox polymerization techniques

- Cerium (IV) ions used in synthesis PMMA-b-PGA copolymers based on using redox polymerization.
- Thermal analysis shows compatibility of two different segments from DSC thermal analysis
- Tensile mechanical test shows considerable decrease in tensile stress and increase in elongation values with the increase of PGA content in the block copolymer

Nitroxide-mediated process

- Preparation and characterization of PS-b-PGA and PVAc-b-PGA block copolymers.
- Thermal analysis showed that PGA is forming miscible and compatible block with PS and PVAc.

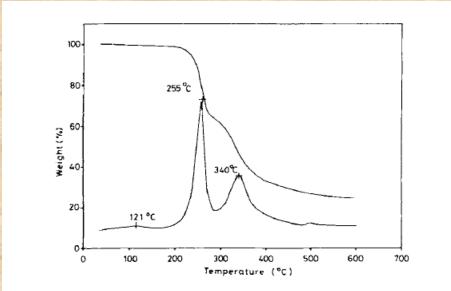


Figure 6 TGA curves of PVAc-b-PGA block copolymer (run no. 5 in Table II).

Controlled/living Free radical polymerization

- Characteristics of Living/Controlled radical polymerization.
- Requirements for living/controlled free radical polymerization.
- Living/controlled radical polymerization methods
 - Dithiocarbamate iniferters
 - Atom transfer radical polymerization (ATRP)
 - Reversible addition-fragmentation transfer (RAFT)

Scheme 6.7 The reaction of hydroxyl terminated poly(epichlorohydrin) with sodium diethyl dithiocarbamate to produce *N*,*N*-diethyl dithiocarbamate-poly(epichlorohydrin) (R is 1, 4-butanediol).

Scheme 6.8 Proposed reaction mechanism for the synthesis of *N*,*N*-diethyl dithiocarbamate-glycidyl azide polymer photoinitiators by the reaction of *N*,*N*-diethyl dithiocarbamate-poly(epichlorohydrin) photoinitiators with sodium azide in DMF (R is 1, 4-butanediol).

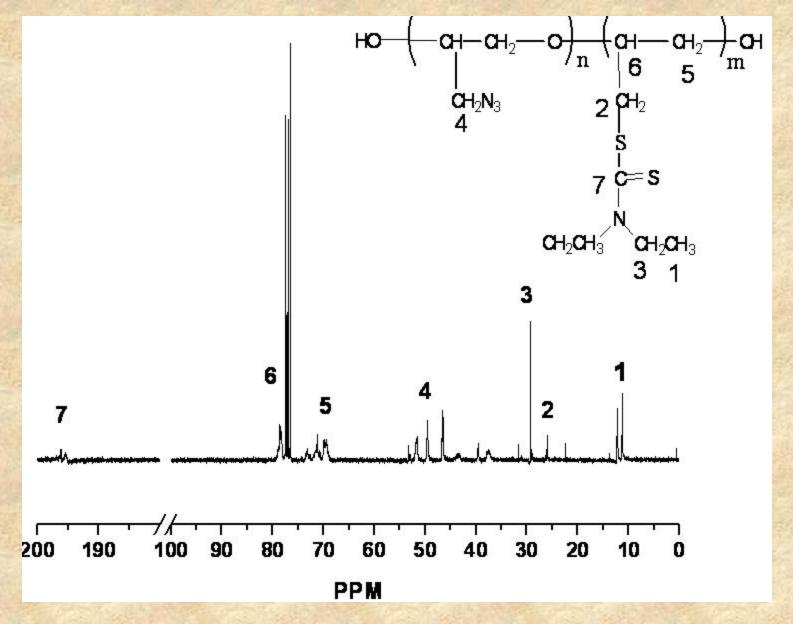


Figure.1. ¹³C NMR(CDCl₃) spectrum of GAP Macro-initiators.

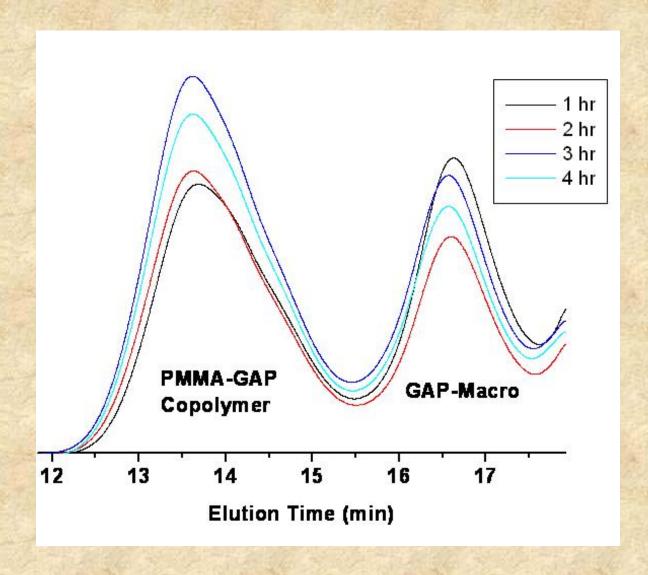


Figure 2. GPC profiles of photopolymerization of methyl methacrylate in toluene initiated by GAP-Macroinitiator.

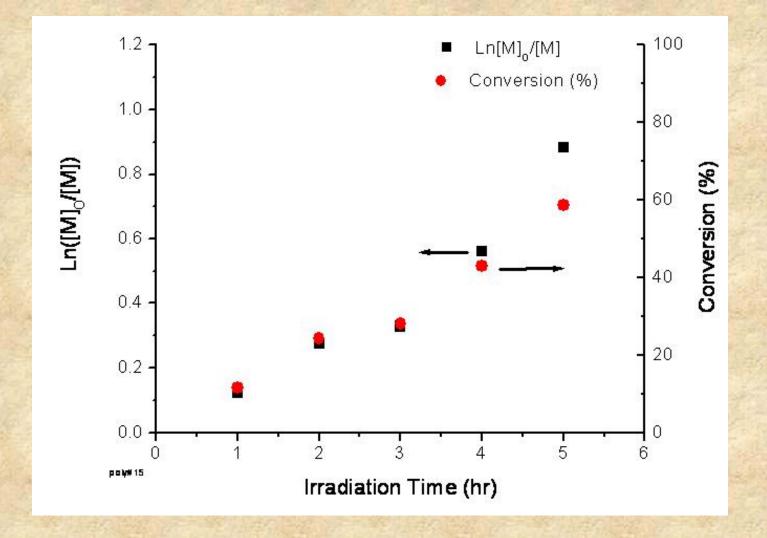


Figure 3 First-order time- conversion plots for the photopolymerization of MMA in toluene initiated by GAP-g-DDC ([GAP-g-DDC]/ [MMA] =0.014).

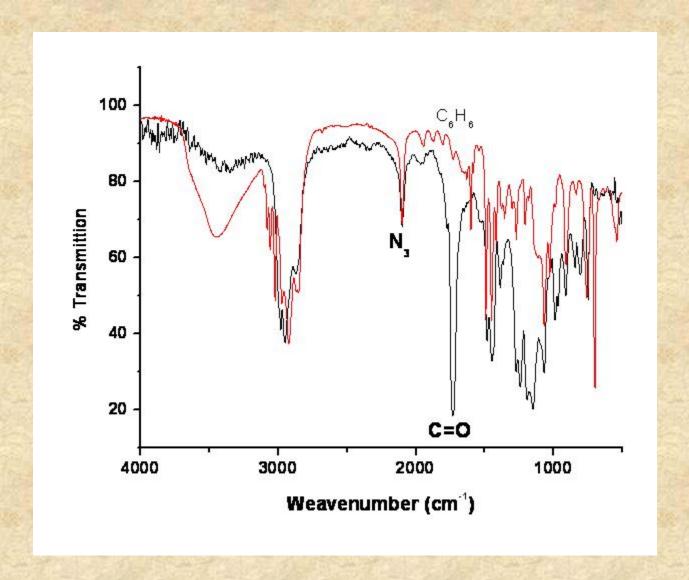


Figure 4 FT-IR spectrum of PMMA-g-GAP (black line) and PSt-g-GAP (red line) copolymer.

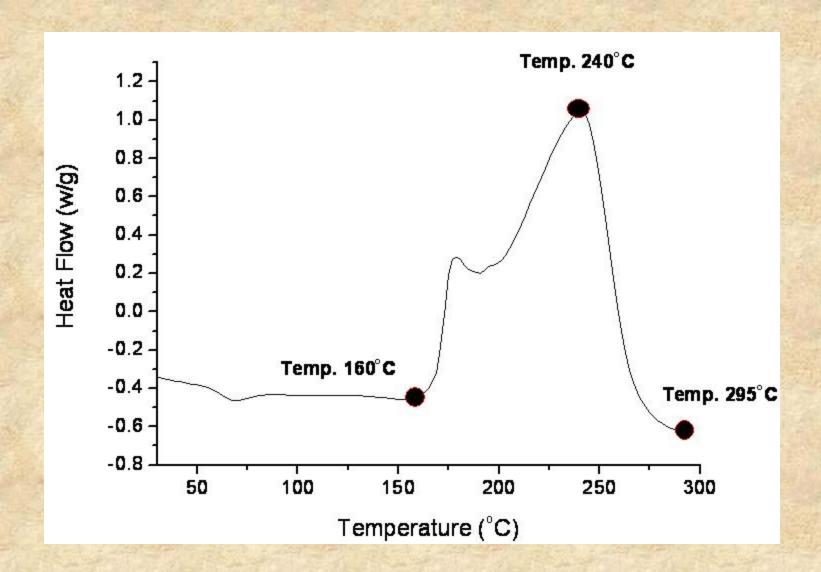
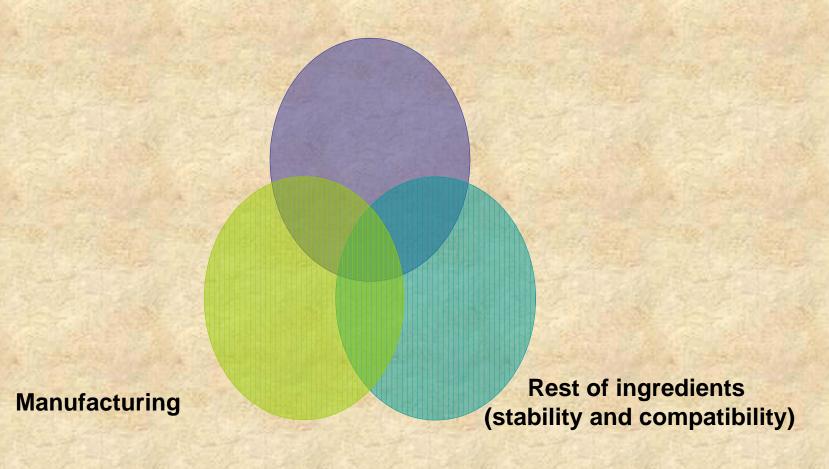


Figure 5 DSC traces of PMMA-g-GAP copolymer (1.159 mg).

Energetic thermoplastic polyurethane

- Thermoplastic polyurethane (TPU) is an (ABA)n or AB type thermoplastic elastomer.
- The constitution of A and B in this linear block copolymer and their sequence length play an important role in the physical properties of TPEs.
- The chemical structure of hard and soft segments and their ratio form an integral part of molecular design for an optimum TPE binder.

Polymerization techniques

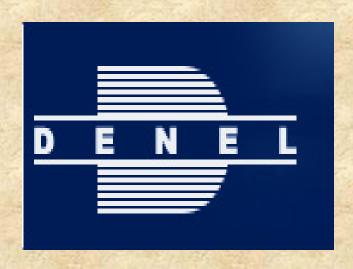


CONCLUSIONS

- Energetic thermoplastic elastomers and polymerization techniques.
- Polymerization techniques affect the final properties.
- Polymeric binder based on using economical polymerization techniques and invariable properties (physical and chemical) is the main requirements for 21st century IM.

ACKNOWLEDGEMENTS

Authors would like to acknowledge NASCHEM, a division of Denel Pty Ltd for financial support.



Innovation ... Delivered.

Development Toward the Large Scale Synthesis of TEX

Dr. Sarah A. Headrick



Background



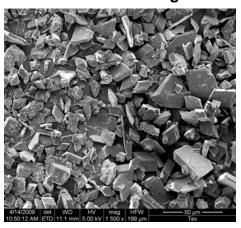
- Development of novel Insensitive Munitions (IM) is a top priority for the US government
 - IM materials respond only when specifically initiated
- IM materials are targeted to replace legacy materials such as RDX
 - RDX is not IM
 - RDX is environmentally unfriendly
- Novel IM material is TEX
 - Low solubility = environmentally friendly
 - Easily synthesized from inexpensive starting materials
 - Simple, two step process provides high producibility and low cost
 - Energy resultant mainly from caged chemical structure
 - High energy with low sensitivity

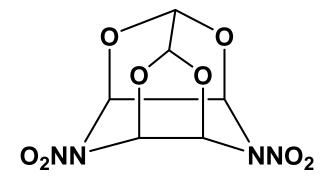
TEX is inexpensive, producible IM material of the future



	RDX	NTO	TEX
Density (g/cc)	1.82	1.91	1.99
VOD (ms/@TMD)	9045	8328	8683 (calc)*
Impact (ABL, cm)	3.5	N/A	33
Friction (lb@8 ft/sec)	324	N/A	800
ESD (Joules)	0.22	0.91	0.43
Onset (°C)	234	270	300

*Calculated using Cheetah 3.0





Excellent IM improvement over RDX



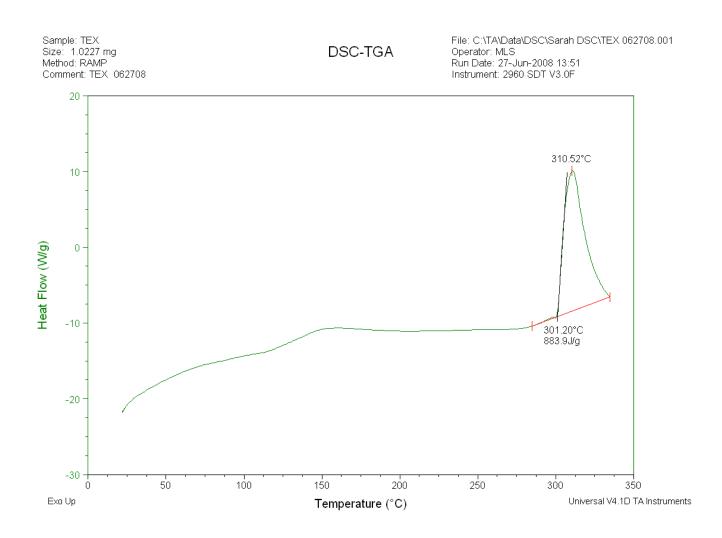
Two step synthesis from glyoxal

- Completed on 2 and 10 g scale at AES
- Material hazards tested and characterized via DSC

Hazards Test	TEX	
Impact	51 cm	
ABL Friction	210 lbs @ 8 ft/sec	
ESD	0.025 J	

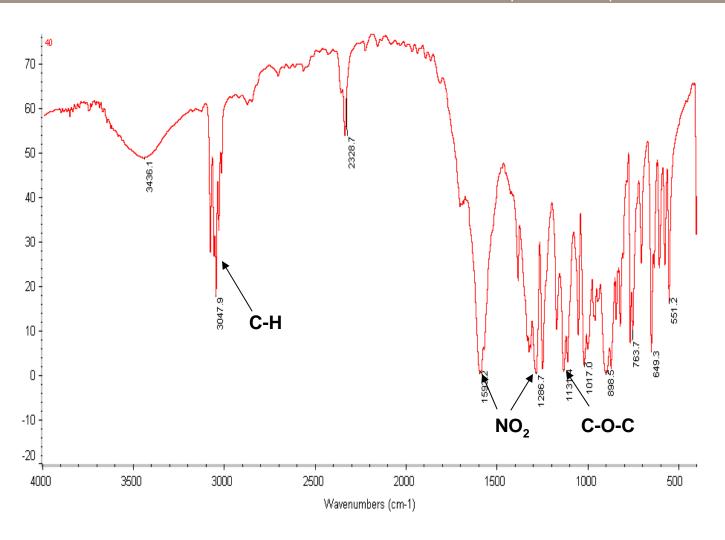
TEX from facile, two step process





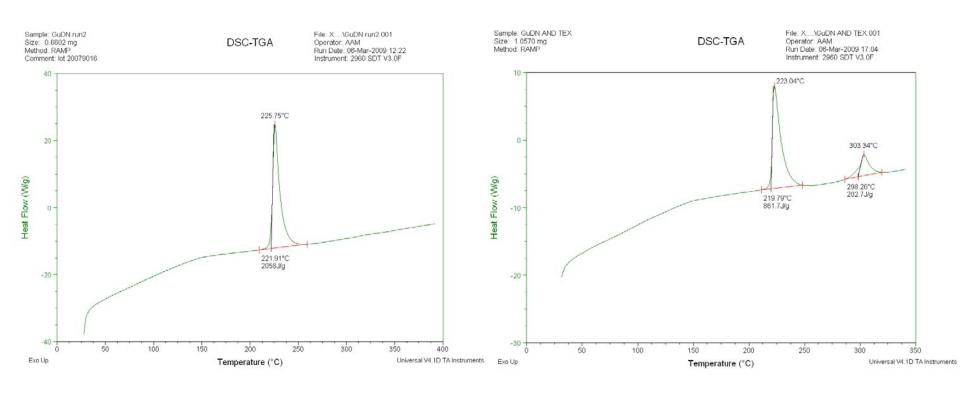
Clean, sharp exotherm peak indicates purity





High quality TEX

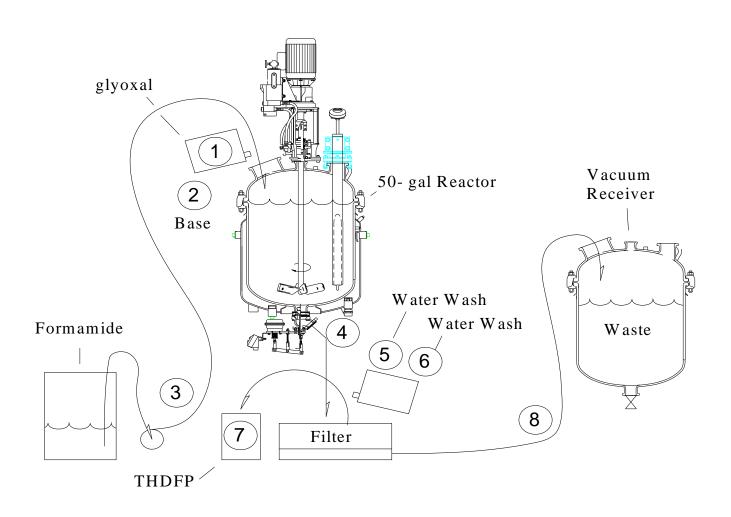




- TEX compatibility tested with NTO, GuDN, NC, NG, RDX and NQ
 - Compatible with all materials

TEX has exceptional compatibility

A premier aerospace and defense company

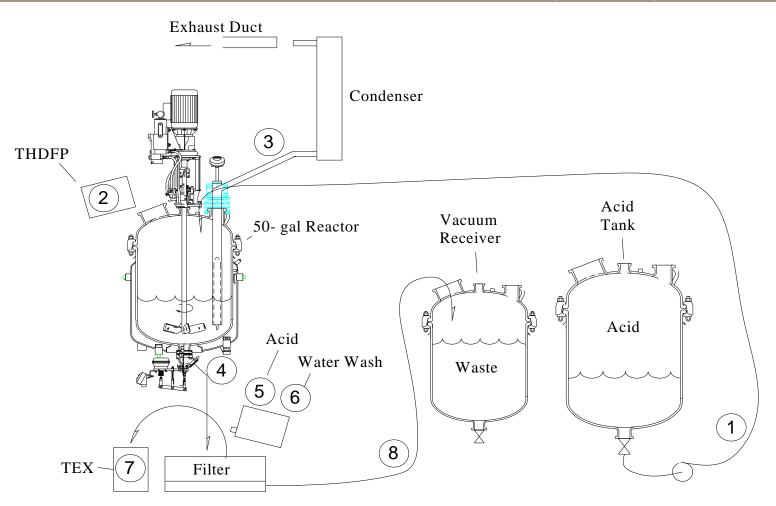


Predictable, inert reaction

Pilot Scale TEX Flow Diagram



A premier aerospace and defense company



Easy, fast nitration

Future Pilot Scale Synthesis



A premier aerospace and defense company

- TEX to be synthesized in AES's new pilot plant
 - Built in 2008
 - Designed for manufacture of specialty materials
 - Explosive and inert
 - Air permitted
 - Sited for 10,000 lbs of explosive
 - 2 L to 100 gallon capacity reactors
 - Flexible configuration
 - Support buildings for additional storage
 - Conductive flooring throughout





Pilot Plant open and ready for business

Pilot Plant Safety Features



A premier aerospace and defense company



Loading dock for transporting materials

- Provides minimal movement for sensitive materials
- Eliminates need for heavy lifting

Separate control room allows for remote capability

- State of the art PLC system including 7 cameras
- Remote control of pumps, stirrers, heating, cooling, dump valves and two electrical outlets



Necessary safety features in place

Flexible Facility



A premier aerospace and defense company



Small scale reactors move in and out

- Medium scale (10 and 20 L) on rolling stands
- Multiple heating, cooling, steam, vacuum, compressed air and ventilation connections
- Easily changes configuration
- Permitted for all kinds of processes





Flexible to fulfill customer needs

Support Utilities



A premier aerospace and defense company



- Acid storage tank
- Vacuum receiver tank
- Acid neutralization tank



- Glycol heating and cooling system
- Drown tank available for exotherms



All necessary utilities provided

Technical Results



TEX has been synthesized on small scale

- Quick, two step process
- Material characterized by DSC
- Material DSC compatibility tested with several materials
 - Compatible with those tested
- Future work to complete pilot scale synthesis of TEX
 - To be performed in AES new pilot plant
 - Construction completed in 2008
 - Fully equipped for energetic and non-energetic reactions (TEX and THDFP)

AES has manufacturing capability for excellent IM material

Conclusions



TEX is a novel IM material

- Inexpensive to produce
- Simple chemistry yields high producibility
- Quick reaction times yields fast manufacturing of production quantities

AES Energetics Pilot Plant

- Fully constructed
- Exceeds all necessary industry safety standards
- Fully flexible for various operations
- All necessary utility support included

AES Pilot Plant open and ready for business

Process Improvement Studies for Scale-Up of HNS at Holston Army Ammunition Plant

Dr. Jacob Morris*, Gary Clark, Dr. David Price BAE SYSTEMS OSI, Holston Army Ammunition Plant





Background - HNS

- Thermally stable energetic material
- Moderate sensitivity
- Broad range of uses:
 - Military, aviation, space applications
 - Oil and gas well perforating
 - Detonating cords
 - Exploding foil initiators
 - Crystal modifying additive in TNT



$$O_2N$$
 O_2N
 O_2
 O_2N
 O_2
 O

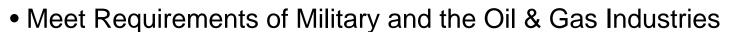
2,2',4,4',6,6'-Hexanitrostilbene (HNS)

- $m.p. = 316 318 \,^{\circ}C$
- Detonation Velocity: 7120 m/s
- Oxygen Balance: -67.6% m/m
- Heat of explosion: 4393 kJ/kg
- ERL Impact Sensitivity: 63 cm



Program Objectives

- Viable Process for Manufacture of HNS at HSAAP
- Use Existing HSAAP Infrastructure
- Competitive Cost



- Thermal Stability-Deeper Wells, Higher Temperatures
- Formulation-amenable







Known Routes: 1-Step Reactions

$$O_2N$$
 O_2N
 O_2N

- Shipp (1964): NaOCI, THF, MeOH
- Kompolthy (1976):, Co/Cu complex, O₂, Base, Polar Aprotic Solvent (PAS)
- Duffin & Golding (1984): Carboxylate base, O₂, PAS
- Duffin & Golding (1987): CuCl₂, Carboxylate base, PAS



Known Routes: Multi-Step Reactions

$$\begin{array}{c|c} CH_3 & NO_2 \\ \hline TNT & NO_2 \\ \hline \\ CI \\ \hline \\ O_2N \\ \hline \\ NO_2 \\ \hline \\ NO_3 \\ \hline \\ NO_2 \\ \hline \\ NO_3 \\ \hline \\ NO_3 \\ \hline \\ NO_4 \\ \hline \\ NO_4 \\ \hline \\ NO_5 \\ \hline \\ NO_5$$

- Kompolthy (1976): HNBB, O₂, Copper complex, Base, PAS
- Gilbert (1980): HNBB, O₂, Copper complex, Base, PAS
- Sollott (1981): TNBCI, THF, Methanol, Base
- Duffin & Golding (1984): HNBB, Carboxylate base, O₂, PAS



Challenges

- Shipp process: sub-ambient, requires binary solvent system (THF/MeOH)
 - THF-expensive, toxic, flammable, peroxides
 - Recovery and make-up of THF/MeOH
- Other processes require polar aprotic solvents; i.e., DMSO, DMF, HMPA
 - PAS are expensive and not recoverable in-house
 - PAS are not recoverable externally with explosive residue
- High production cost associated with previous processes
 - Large excess of solvent, base, PAS, and/or metal complex
- Need a 1- or 2-step process with low complexity & cost, and robust purification



HSAAP Development Work

Two Step Process

- 1. Vary Shipp conditions to maximize HNBB
 - No THF, higher temperature, added base

2. Use Gilbert process to convert HNBB to HNS

- DMSO, copper amine complex, air

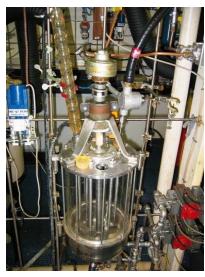


Optimization - HNBB Synthesis

$$\begin{array}{c} \text{CH}_3\\ \text{O}_2\text{N} \\ \text{NO}_2 \\ \text{NO}_2 \\ \text{TNT} \\ \end{array} \begin{array}{c} 6\% \text{ NaOCI, NaOH}\\ \text{MeOH, 40-45 °C} \\ \text{O}_2\text{N} \\ \end{array} \begin{array}{c} \text{NO}_2\\ \text{NO}_2 \\ \text{NO}_2 \\ \end{array} \begin{array}{c} \text{NO}_2\\ \text{NO}_2 \\ \text{NO}_2 \\ \text{NO}_2 \\ \end{array} \\ \begin{array}{c} \text{65-70\% crude yield}\\ \text{>90\% HNBB, <7\% TNT} \\ \end{array}$$



- NaOCI:base ratio (pH control)
- Reaction temperature
- Bleach addition rate
- HNBB Drying
 - Methanol wash removes water without need for drying
- Crude vs. Purified HNBB
 - No purification saves time and money







Optimization - HNBB Synthesis

Bleach Addition Rate Study

Bleach Addition	Yield	HPLC Area %		Assay Yield
Rate	Wt. %	HNBB	TNT	%HNBB
R ₁ (Fastest)	73	96.4	3.7	70.4
R ₂	69	94.3	4.9	65.1
R ₃	68	89.1	9.7	60.6
R ₄ (Slowest)	66	78.6	20.4	47.2

Faster addition affords more HNBB at a higher purity



Optimization - HNS Synthesis

HNBB to HNS Optimization:

- Amount of Copper catalyst
- Reaction Time
- Amount of DMSO and number of recycles
 - Optimized to 1 virgin and 3 recycles





Optimization - HNS Synthesis

Reaction Time (Hours)	DMSO Ratio (mL:HNBB)	Catalyst Ratio (Cat:HNBB)	HNS Yield Wt. % (From TNT)
>20	High	High	28.5
<10	High	High	29.1
<10	Low	High	39.2
<10	Low	Low	41.5

- Reduction in reaction time gives similar yields (lower overall cost)
- Reduction in solvent leads to increase in yield (and lower cost)
- Reduction in catalyst leads to slight increase in yield (and lower cost)



Optimization – HNS Purification

- Crude HNS-I has dark brown color, contains 8-10% HNBB
- Product failed Thermal Stability Testing
- HNS has poor solubility in common solvents
- Recrystallization from PAS/anti-solvent adds significant cost
- Two purification routes developed:
 - HNO₃ Digestion
 - HNO₃ Recrystallization





Optimization – HNS Purification

HNO₃ Digestion

Conditions	Wt. % HNO ₃	VTS (260°C) mL/g/mLghr	Bulk Density g/mL	Wt.% Recovery
Targeted Parameters	-	<0.6/<0.6	0.8	-
Slow Cool	70	0.7/0.2	0.5	85
Fast Cool	80	0.6/0.1	0.3	91
Fast Cool	90	0.3/0.2	0.4	87
Slow Cool	90	0.6/0.1	0.7	74
10x Scale-up of Above	90	0.2/0.1	0.6	83
21x Scale-up of Above	90	0.2/0.1	0.6	86

⁻ Higher concentration of nitric acid affords good recovery, reasonable density, and acceptable thermal stability.



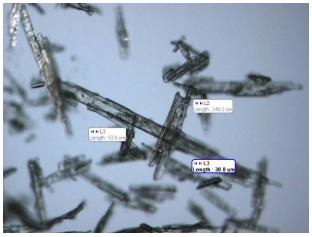
HNS Purification – HNO₃ Digestion

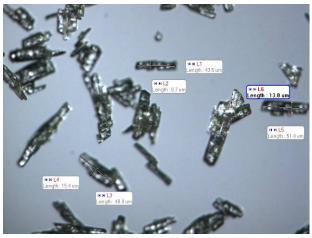
Crude HNS: d=0.25 g/mL



Length: 400 – 800 micron Width: 12 – 20 micron

Fast cool: d=0.4 g/mL





Slow Cool: d=0.7 g/mL



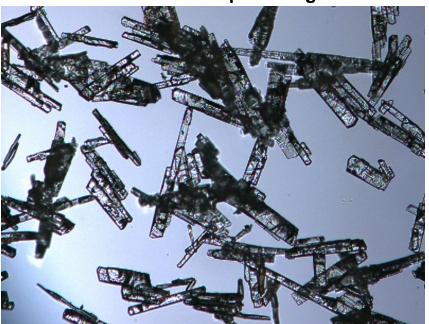
HNS Purification – HNO₃ Digestion

90% HNO₃ Digestion

Small Scale: d=0.7 g/ml



Lab Scale-Up: d=0.6 g/ml



VTS: 0.6/0.1 VTS: 0.2/0.1



HNS Purification - Recrystallization

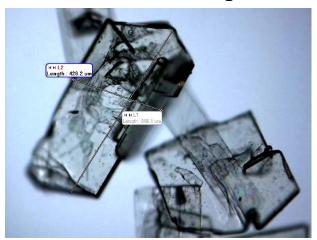
90% HNO₃ Recrystallization

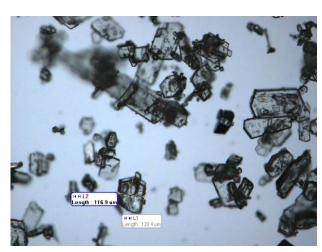
Conditions during cooling	VTS ml/g/ml/ghr	Bulk Density g/ml	% Recovery
Targeted Parameters	<0.6/<0.6	>0.8	_
No Stirring	0.7/0.2	0.6	64
Normal Stirring	0.4/0.1	0.6	70
Slow Stirring	0.3/0.1	0.8	68
Slow Cooling and Stirring	0.5/0.4	1.0	68
Scale-up of above to ~1 lb scale	0.6/0.3	0.85	70



HNS Purification - Recrystallization

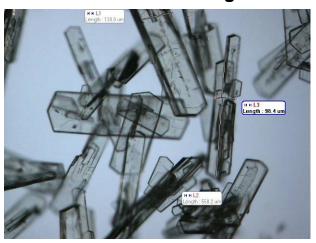
No Stir: d=0.6 g/mL

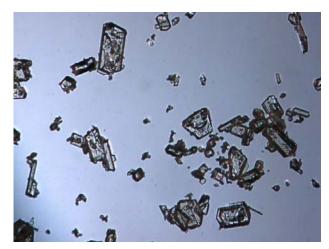




1/2 Normal Stir: d=0.8 g/mL

Normal Stir: d=0.6 g/mL



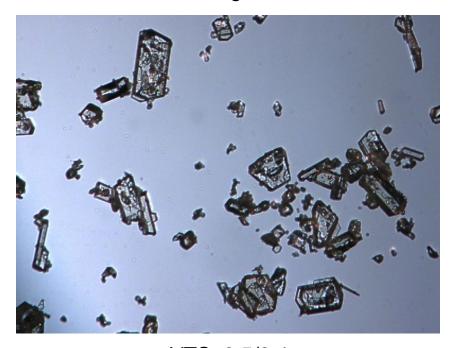


Slow Cool & Stir: d=1.0 g/mL



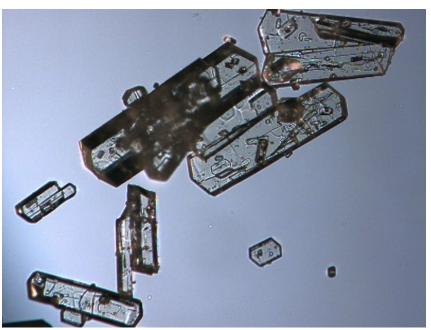
HNS Purification - Recrystallization

Small Scale d = 1.0g/mL



VTS: 0.5/0.4

Lab Scale-up (\sim 1 lb scale) d = 0.85 g/mL



VTS: 0.6/0.4



HNS Process Optimization

- HNS Reaction conditions have been optimized
- Two viable HNO₃ purification routes:
 - Digestion:
 - VTS: 0.2/0.1 mL/g/mL/ghr
 - Bulk Density: 0.6 g/mL
 - Recrystallization:
 - VTS: 0.6/0.4 mL/g/mL/ghr
 - Bulk Density: 0.85 g/mL





Conclusions and Future Work

- Viable 2 step process for HNS identified
- Robust purification process identified
- All material processed passes thermal stability test
- Process is highly cost-competitive
- Further optimize weight yield of crude HNS
- Optimize scale-up cooling and agitation rates for maximum densities of purified HNS



Holston Army Ammunition Plant



HNS manufacture at HSAAP by FY 2010



Acknowledgements







Synthesis and Scale-Up of TATB

Dr. David Price

BAE Systems/HSAAP

May 2009







TATB Program Goals

Low Cost/High Volume Supplier

- Inclusion in Many New IM Formulations
- Good Fit for Existing Holston Infrastructure
- Minimal Initial Capitalization
- Short Time to Production Quantities
- Equivalent Quality to Traditional TATB
 - Similar Shock Sensitivity in PBXN-7 needed...







Technical Issues of Earlier TATB Efforts

- In PBXN-7, OSI TATB (5 micron) performed well in all examined aspects except:
 - Shock sensitivity:

Material Tested	Average Pellet Density, g/cm ³	NOL LSGT, cards/kbars	Detonation Velocity, m/s
PBXN-7 manufactured by NSWCIH Yorktown Det with ATK TATB	1.781	50% kbar increase	7464
PBXN-7 with OSI TATB (supplied by OSI)	1.789	70% kbar increase	7572
Historical data ^a	1.78		7660

Reduction in sensitivity thought to be caused by small particle size and/or crystal morphology of TATB (as compared to traditional TATB (50 micron)





Available Technologies

- Traditional Trichlorobenzene (TCB) Route- "Benziger Route"
 - Harsh conditions; waste streams
 - TCB not domestically available





Holston TATB Synthesis Method

New 2-Step Process/Synthesis Route Developed by OSI Scientists

- Scalable on the Holston Infrastructure
- Good Fit for Agile Manufacturing Plant (G-10)
- Multiple Sources Identified for Raw Materials-Including CONUS

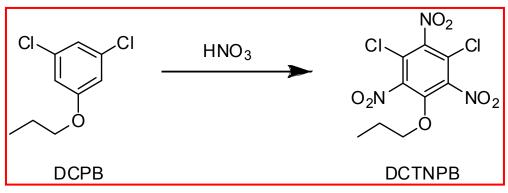
- Purity comparable to reference (Bridgwater)
- Particle size typically 40 microns
- Produced ~20 lbs TATB to date





Laboratory Nitration of DCPB

- DCPB is fed as a liquid into nitric acid
- Initial reaction is mildly exothermic
- Reaction performed several times in 5 gal reactor (10 lb batch size)
- Yields ≥ 95%
- Purity typically > 99%







DCTNPB (3,5-Dichloro-2,4,6-trinitropropoxybenzene)

$$O_2N$$
 O_2
 O_2N
 O_2
 O_2
 O_2
 O_2
 O_3

Chemical Formula: C₉H₇Cl₂N₃O₇ Molecular Weight: 340.07

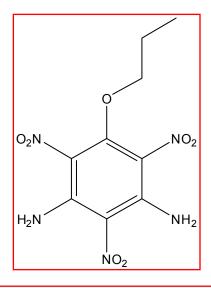
- Insensitive Intermediate
- Melting Point = 121°C
- Exotherm Onset = 220°C (as determined by DSC)
- Impact Sensitivity > 80 cm (Holston Method)





Laboratory Amination of DCTNPB

- DCTNPB is aminated in toluene with gaseous ammonia at high temperature and under pressure (similar to Benziger route)
- Reaction Scaled to 1 mole (2 gal Parr)
- Yields are ~ 75%
- Known Impurities:
 - -Ammonium diaminopicrate (ADAP)
 - -3,5-Diamino-2,4,6-trinitropropoxybenzene (PDAP-seen in early development, not detected in current process) -Mp = 214 C







Formation and Elimination of Ammonium Diaminopicrate (ADAP)

Average % ADAP Pre-Wash

Lot 1	0.15%
Lot 2	0.15%
Lot 3	0.58%

Average % ADAP Post-Wash

Lot 1	0.04%
Lot 2	0.02%
Lot 3	0.02%

 Washing with hot water until wash water becomes light yellow lowers ADAP contamination considerably





TATB Analytical Summary

Batch 1 Batch 2

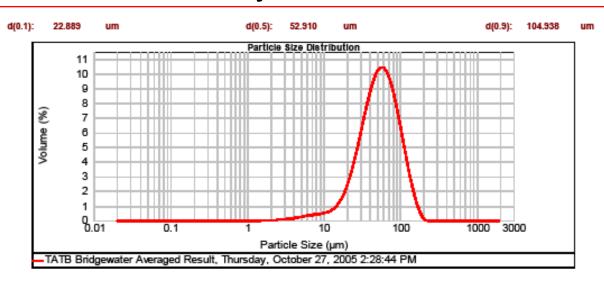
DSC	354°C
TGA	250°C (0.78%),
	325°C (18.4%),
	400°C (78.7%)
Mean particle	40.7μm
size	
% ADAP	0.03%
VTS (100C, 48	0.1167
hrs)(mL/g)	
% Chloride	0.12%

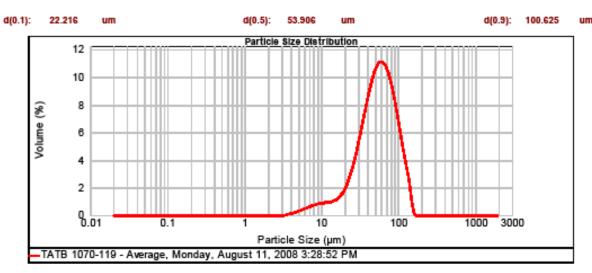
DSC	354°C
TGA	250°C (<mark>0.42%</mark>),
	325°C (16.6%),
	400°C (77.1%)
Mean particle	34.4μm
size	
% ADAP	0.02%
VTS	N/A
% Chloride	0.10%





Particle Size Analysis



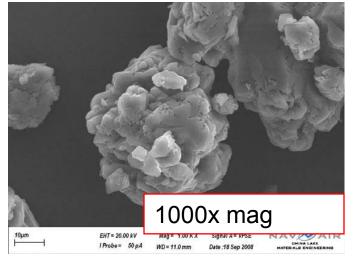




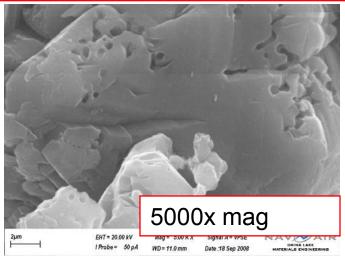


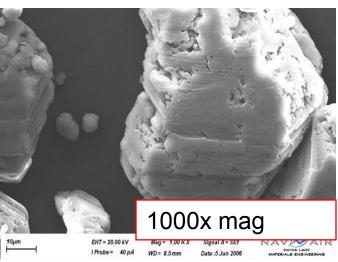


SEM Analysis

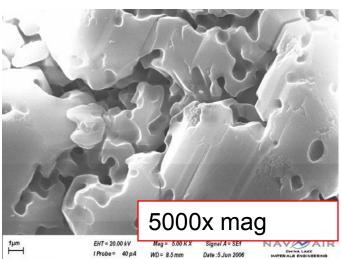










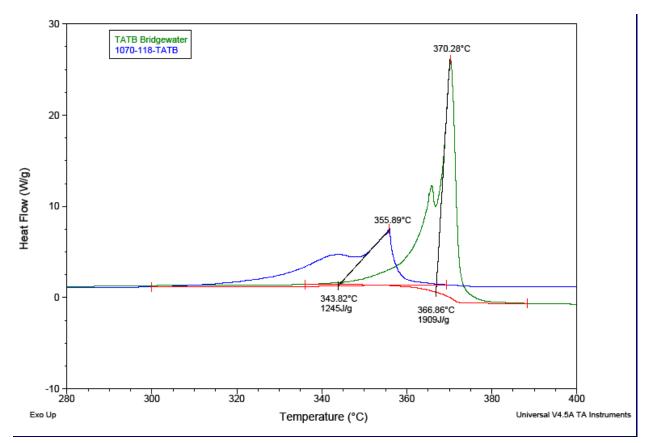






DSC phenomenon

DSC of new TATB found to be significantly different than traditional **TATB**



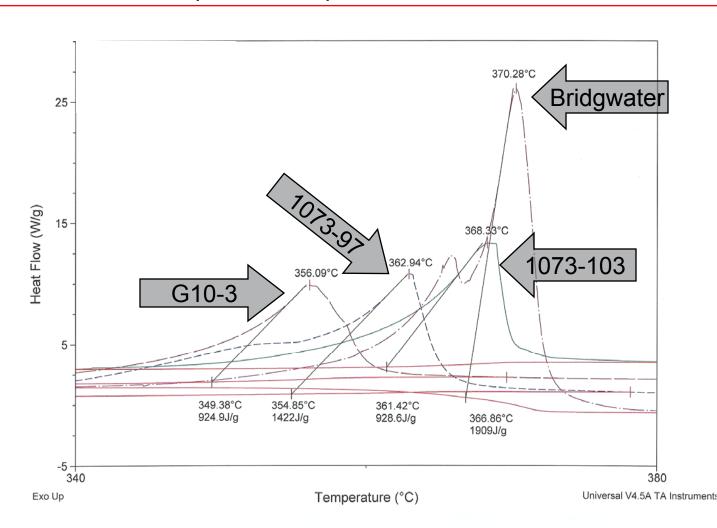
*All DSCs performed at 5C/min unless otherwise noted

- DSC* not affected by:
- Glass vs SS reactor
- Wet or dry amination
- Amination temp.
- Purity
- Digestion in DMSO
- Amination under N2





TATB DSC (5°C/min)

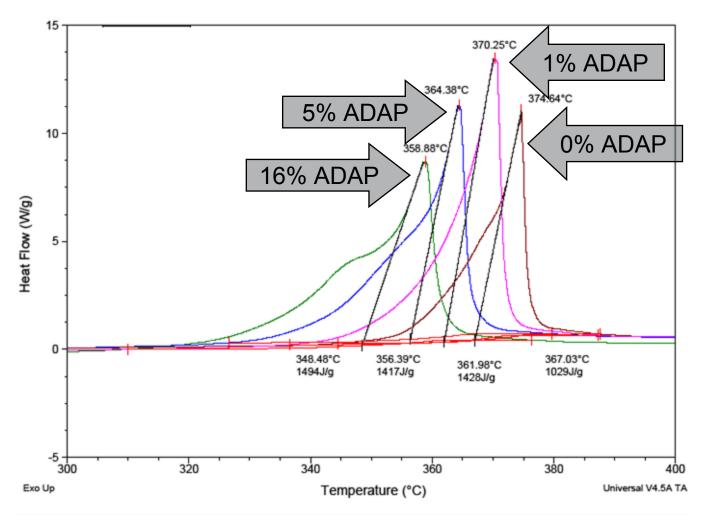


- •G10-3 is production run using previous dibromoanisole aqueous route.
- •1073-97 is from DCTNPB route, recrystallized from DMSO.
- •1073-103 is RT aqueous amination of **DCTNPB** (90% yield).

ADAP spiking of aminations-TATB DSC (5°C/min)





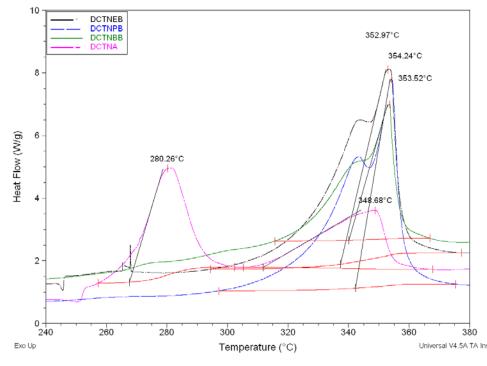


- Aminated TCTNB w/ varying levels of ADAP present in reaction medium
- TCNTB does not afford ADAP.
- ADAP levels in TATB from spiked reactions are consistently low.

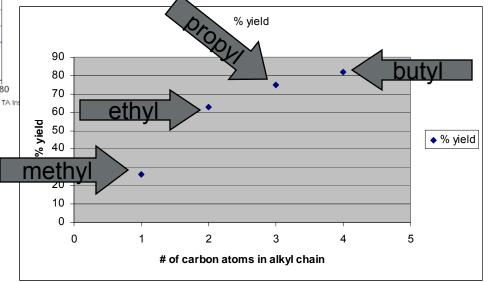


Effect of varying length of alkyl chain on yield and DSC (5°C/min)





- ➤ Amination of DCTNA (methyl group) gives low yields.
- ➤ Ethyl, propyl, and butyl groups show no effect on DSC.
- ➤ Yields modestly increase as length of alkyl chain increases.







Formulations: PBXN-7

- Several lab batches
- Consistent process and product

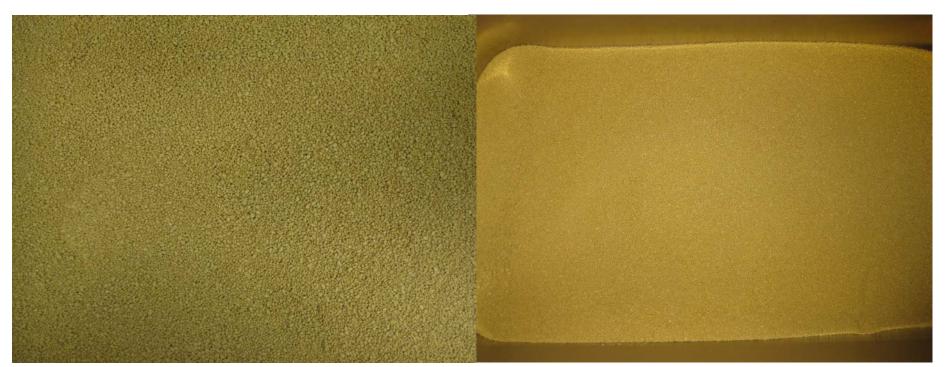
Screens (%Pass)	batch 1	batch 2	batch 3	composite
#6	met spec	met spec	met spec	met spec
#14	met spec	met spec	met spec	met spec
#18	met spec	slightly out	met spec	met spec
#100	met spec	met spec	met spec	met spec
Bulk Density (g/cm ³) (Naval)	met spec	met spec	met spec	met spec
Composition	met spec	met spec	met spec	met spec
Moisture	N/A	N/A	N/A	met spec
Impact Sensitivity (ERL, cm)	N/A	N/A	N/A	met spec
VTS by PT Method (100°C, 48h)(mL/g)	N/A	N/A	N/A	met spec
Press Density (g/cm ³)	N/A	N/A	N/A	slightly out (low)
Comments				Blend of 1,2,and 3





Formulations: PBXW-14

- One batch made in lab
- Successful integration of TATB made from the new OSI method into the existing W-14 formulation procedure.
- No performance data at this time.







Conclusions

- Two-step TATB manufacturing process developed at **HSAAP**
- Process is robust and safe
- Quality equivalent to traditional sources of DOD "grade" material (Bridgwater)
- Competitive cost to traditional TATB
- Process and cost optimization ongoing
- Difference in thermal properties (DSC) appear to be caused by ADAP impurity in process
- TATB currently appears to be a "drop-in" replacement in DOD formulations (waiting for performance testing)





Acknowledgments

- **BAE Systems:**
 - Neil Tucker and Jim Haynes-Nitrations and Aminations (lots of them!)
 - Ed LeClaire Agile Plant Mgr. & Process Development
 - Lisa Hale and Kelly Guntrum

 Analytical Support
 - Jim Owens Analytical Method Development & Support
 - Brian Alexander PBXN-7 formulation
- Navy:
 - Al Stern, Brad Sleadd, Tim Mahoney -Useful discussions, suggestions, and direction
- **ONR Mantech Program-Funding**
- Chuck Painter-Mantech director





Processing and Characterization of Nano RDX

Victor Stepanov and Wendy Balas (ARDEC)
Prof. Lev Krasnoperov (NJIT)





Introduction



- Common high explosives including RDX, HMX, and CL-20 are vulnerable to accidental initiation
- Accidental initiation may be caused by stimuli including:
 - Bullet or fragment impact
 - Incident shock waves from adjacent detonation
- Sensitivity of a HE to incident energy is associated with:
 - Chemical structure
 - Physical properties (crystal size, shape, defects)
 - Formulation characteristics (binder material /processing)
- Sensitivity generally increases with power



Introduction



- Experimental data and theoretical models indicate that reduction of the crystal size should generally lead to a lowered sensitivity
- Some effects of size reduction include:
 - Smaller size of crystal defects
 - Smaller size of inter-crystal voids
 - Improved mechanical properties
 - Enhanced resistance to plastic deformation
 - Due to a larger number of heterogeneities with smaller dimensions a more homogeneous distribution of incident energy



Objectives



- Develop method for the bulk production of high quality and purity nanocrystalline RDX
- Prepare explosive formulations using nano-RDX
- Determine the effects of particle size reduction on the sensitivity and performance:
 - Shock and impact sensitivity
 - Detonation characteristics:
 - Critical diameter



RESS Process Background



Rapid expansion of supercritical solutions (RESS) using carbon dioxide as solvent was successfully demonstrated to recrystallize RDX with following product characteristics:

- Nano-scale dimensions
- Narrow size distribution
- High purity
 - No residual solvents
- Near-spherical crystal shape

V. Stepanov et al., Propellants, Explosives, Pyrotechnics, 3, 2005



RESS Process



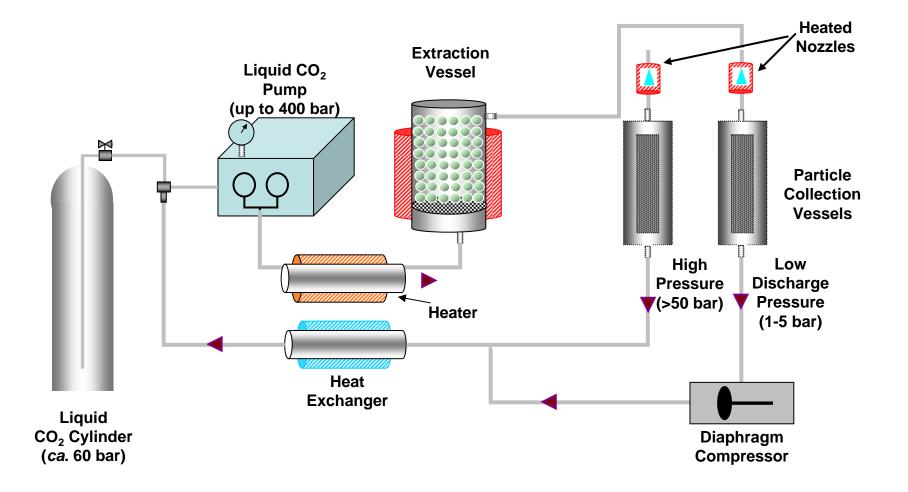
To generate bulk quantities of nano-RDX required for testing, a high throughput RESS process was developed with following characteristics

- Continuous processing
- Solvent (CO₂) Recycling
- Efficient product collection
- Variable discharge pressure operation





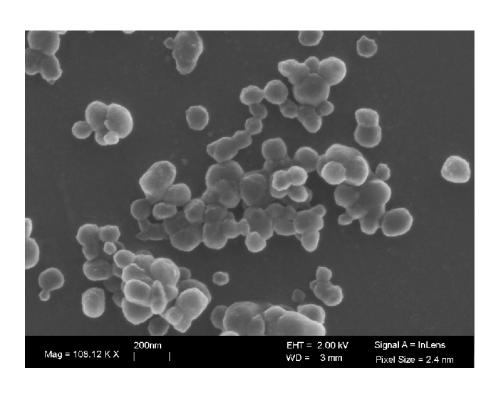
RESS Set-Up with CO₂ Recycling

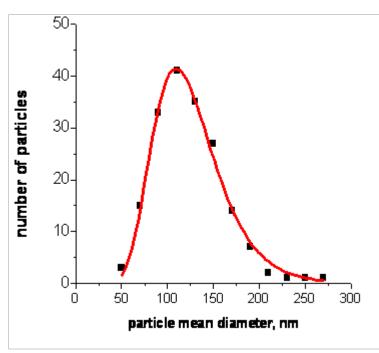






Expansion to Atmospheric Pressure (Type A Nano-RDX)





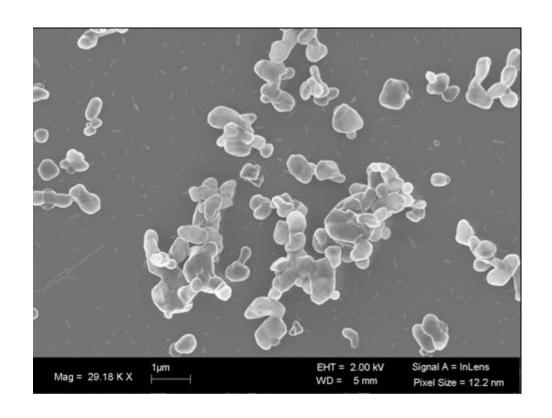
Mean Particle Size: 125 nm

Specific Surface Area (SSA): ~15-20 m²/g





Expansion to 55 bar (Type B Nano-RDX)



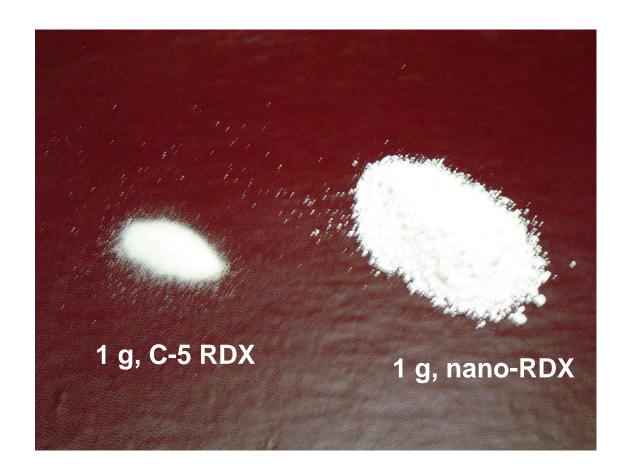
Mean Particle Size: ~ 500 nm

SSA: $5-6 \text{ m}^2/\text{g}$





Bulk image of class-5 and nano-RDX







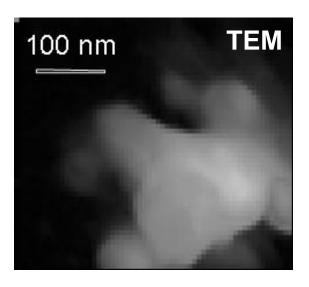
- Sensitivity testing was performed on pure and formulated nano-RDX samples. 4 μm RDX was used as the reference material.
- Formulations consisted of 88 wt. % RDX and 12 wt. % wax
 - Wax applied by slurry coating in H₂O/MEK (90/10)
 - Lecithin used as surfactant to aid dispersion and stabilization
- Sensitivity tests performed:
 - Electrostatic discharge sensitivity
 - ERL type 12 impact test (impact sensitivity)
 - NOL small-scale gap test (shock sensitivity)

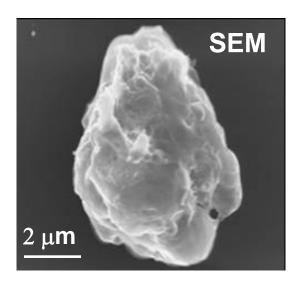


Coating Characterization



Conventional TEM and SEM imaging of wax coated RDX nanoparticles



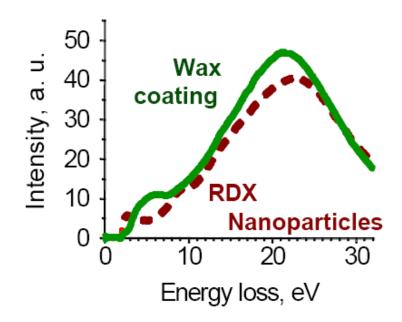




Coating Characterization



 STEM-EELS analysis used to analyze the distribution of wax on RDX. (Prof. Matt Libera, Stevens Inst. of Tech.)

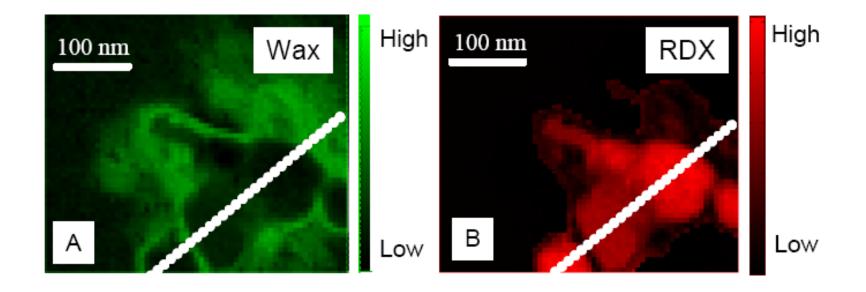


Energy loss spectra of pure wax and pure RDX



Coating Characterization





Spatially resolved maps of the wax (A) and RDX (B) by EELS analysis





Pure and formulated samples tested included

- RDX recrystallized by RESS
 - □ Type A nano-RDX; SSA ~ 15-20 m²/g
 - □ Type B nano-RDX; SSA ~ 5-6 m²/g
- Commercially available RDX
 - 4 micron RDX; SSA ~ 1 m²/g (Reference)
 - Class-5 RDX, ~20 μm mean size (Reference)
 - Class-1 RDX, >100 μm mean size (Reference)





Electrostatic discharge sensitivity test results

- Method 1032, MIL STD 1751A
- Maximum energy loading 0.25 J

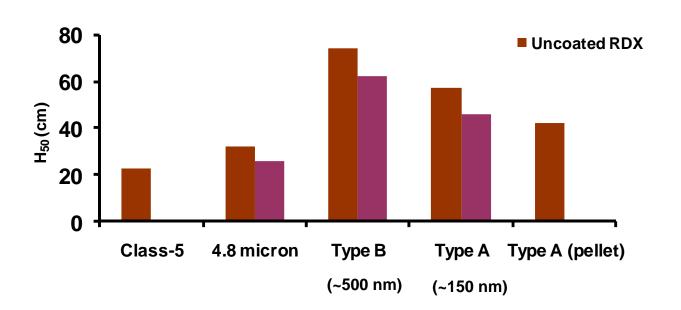
Material	ESD Sensitivity to 0.25 J
4.8 Micron RDX	No fire
Type A nano RDX	No fire
Type B nano RDX	No fire





Impact sensitivity test results

- ERL/Bruceton method 1012, MIL STD 1751A
- Drop height corresponding to 50 % probability of initiation (H₅₀) determined







Shock sensitivity testing

Test description

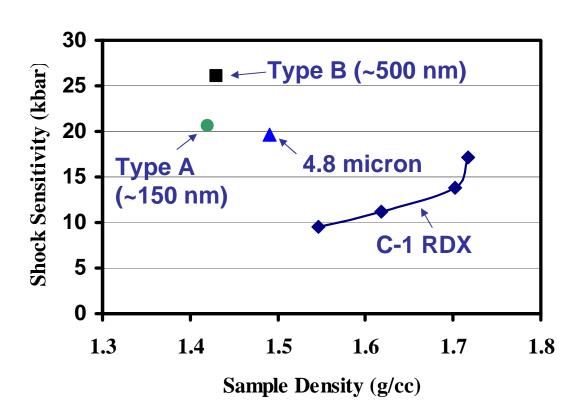
- Small-scale gap test, method 1042, MIL STD 1751A
- Samples pressed at 16,000 psig
- Shock pressure corresponding to 50 % probability of initiation determined





SSGT shock sensitivity test results

Uncoated RDX samples

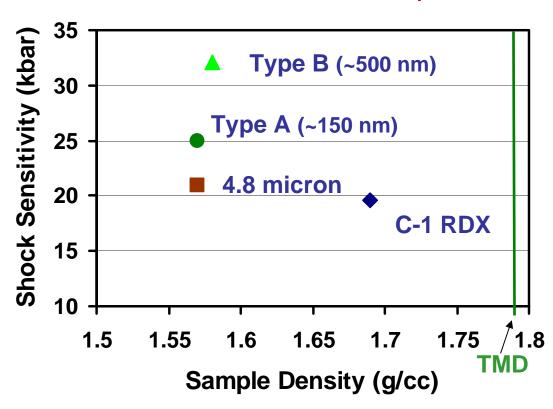






SSGT shock sensitivity test results

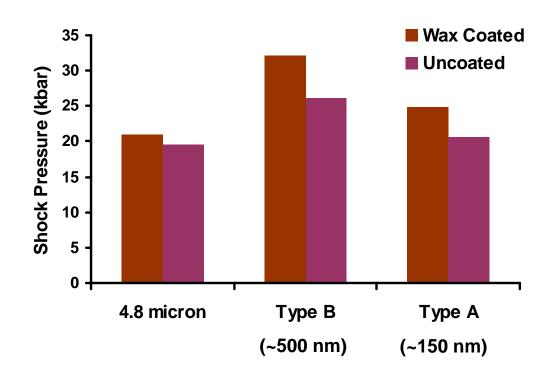
Wax coated RDX samples







Shock sensitivity test results summary





Summary



- Capability to generate bulk quantities of nanocrystalline RDX developed
- Initial testing reveals a substantial reduction in sensitivity towards both shock and impact stimuli of coated as well as uncoated samples



Acknowledgements



ARDEC Contributors

Steven Nicolich, Ted Dolch, Robert Lateer, and Amy Wilson





Thank you!



MINISTÈRE DE LA DÉFENSE

Modelling the response of SRMs to impact loading

DGA/CAEPE/EXP

IMEMTS 2009



DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

SUMMARY

- 1) CAEPE and test facilities
- 2) Analysis tools Thermics and mechanics
- 3) ANSYS/DYNA SRM under impact loading
- 4) CRONOS Hazard areas in case of explosion

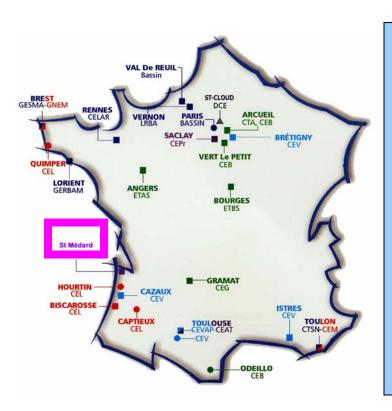






1) CAEPE and test facilities

CAEPE AND DGA



- French MoD / DGA / CAEPE
- St Médard en Jalles (33), 330 employees
- Expertise and testing of SRMs



Performance Security Aging

Major programs:



Tactical (MdCN, AASM, Mistral ...) Strategic (M45/M51, ASMPA)







PROPULSION TESTS

- 2000 tests carried out in 35 years
- 10 ground testing facilities over 3000 ha
- Motors up to 50 t of propellant and 2500 kN of thrust



1st stage ground testing



MESA facility







1) CAEPE and test facilities

SAFETY TESTS

- Tests according to STANAG standards:
 - > SCO, FCO, bullet, light / heavy fragment impact,
 - ➤ Drop, shaped charge jet, sympathetic reaction, ...
- 3 safety areas and a drop test tower
- Specimens up to 30 t / 600 kg of propellant / TNT
- Capability of 200 measurements

DGA/CAEPE













2) Analysis tools

GOALS

CAEPE TESTING ACTIVITIES

- Preparation of complex tests
- Representativeness of partial tests
- Safety level of operations and tests
- Design of tools and measurements
- Test results analysis





DGA PROGRAM MANAGERS

- Advices on architecture and design
- Analysis of critical issues
- Respect of qualification requirements
- Research programs
- Interactions with the weapon system

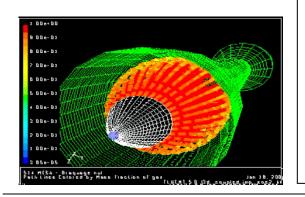






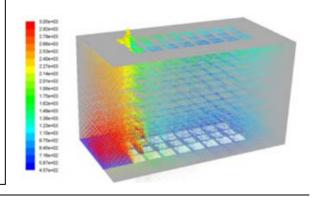
2) Analysis tools

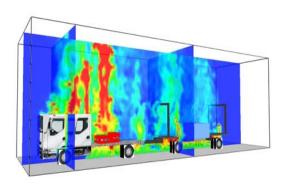
THERMICS



FLUENT / CFX

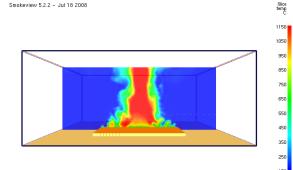
- Fluid dynamics
- Supersonic flaws
- Internal / external
- Motor ignition
- Thermal flux





FDS

- Fire dynamics
- Subsonic flaws
- Propellant, kerosene
- Safety of operations
- Transport, assembly



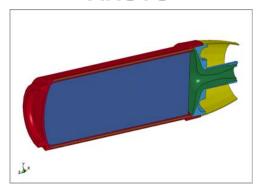




2) Analysis tools

MECHANICS

ANSYS



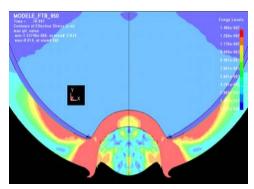
Undamaged

- Storage / flight
- Static / transient
- Multiphysics



Safety margins

DYNA



Failure

- Accidental / hostile
- Low / high velocity
- Reactive / unreactive



Reaction level

CRONOS



Post-failure

- SRM explosion
- Fragment projection
- Blast overpressure



Safety areas



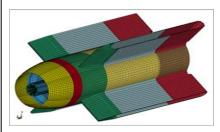




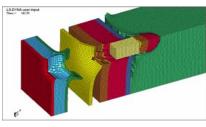
BUILDING THE FE MODEL - 1

Necessary access to detailed and reliable input data

GEOMETRY



Global model



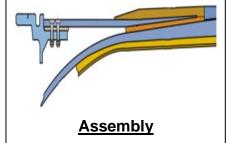
Local model

DGA/CAEPE

FABRICATION



Winding law



CONSTITUTIVE EQUATIONS

Mechanical response:

- Elasticity \mathbf{E}, \mathbf{v} with influence of:

- strain rate C, p

- plasticity, σy, n

- thermal softening, m

- hyperelasticity, C_{ij}, K

- viscosity ... Ei, τi

+ Associated failure criterion

+ Equation of State

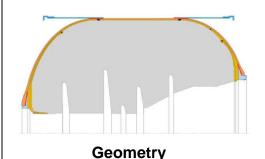




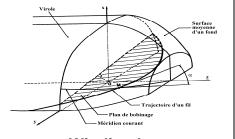


BUILDING THE FE MODEL - 2

Initial model built using uncertain input data



$$\mathbf{C_{ij}} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ & C_{22} & C_{23} & 0 & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ & & & C_{44} & 0 & 0 \\ Sym. & & & & C_{55} & 0 \\ & & & & & C_{66} \end{bmatrix}$$

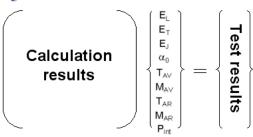


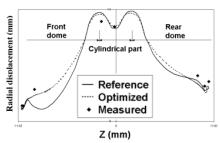
Stiffness matrix

Winding law

Adjustment by means of inverse identification

		T .	
Materials properties	Composite structure	E _L = E _L reference +/- 5%	
		ET = ET reference +/- 20%	
		ET = ET reference -50% and -75% (matrix degradation)	
	Skirts	ET = EC = E reference +/- 20%	
Winding law	Cylindrical part	On = On reference +/- 1°	
	Front dome	Translation of +/- 10°	
		Multiplication by +/- 10%	
	Rear dome	Translation of +/- 10°	
		Multiplication by +/- 10%	
Initial geometry	Prior deformation	P _{int.} = 10 and 20 bar	





Individual parameters influence

DGA/CAEPE

Multivariate analysis

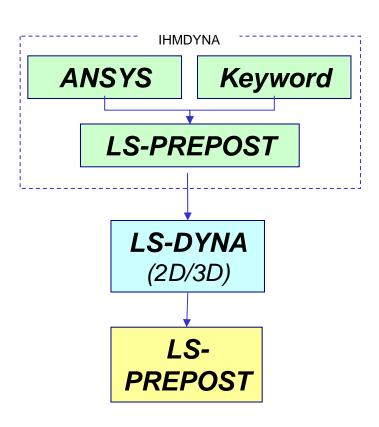
Comparison



DGA



BUILDING THE FE MODEL - 3



Automated generation of input files

- Meshes for projectiles and targets
- Incidence of projectiles
- Multi-layered targets
- Numerical parameters (contact / solver)



12/05/2009

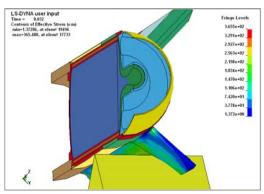




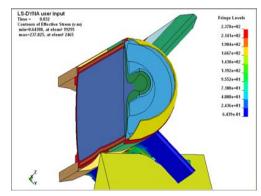




EXAMPLE OF LOW VELOCITY IMPACT







Non-erosive model (FS = infinite)

Optimistic

Real behaviour (FS = numerical)

Needs calibration

Erosive model (FS = material)

Pessimistic

- Strong dependance with numerical parameters
- Erosive criterion not based on material strength
- Model to be calibrated on test results





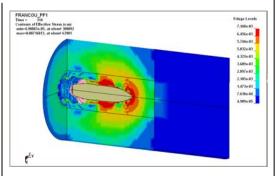


EXAMPLES OF HIGH VELOCITY IMPACT

LS-CYNA start leptor There 2009 Casterns of Reflective Plants Stadis may bit value may 2012 marc-1,1792.1, at shreat 2005 Frings Levels L399-40 1,299-40 1,

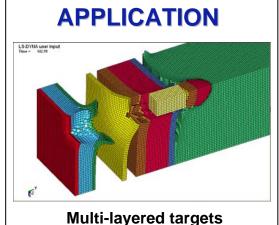
G g spherical projectile

Test testimm
Test test mm
Test test mm
Model testimm
Model t



12.7 mm bullet





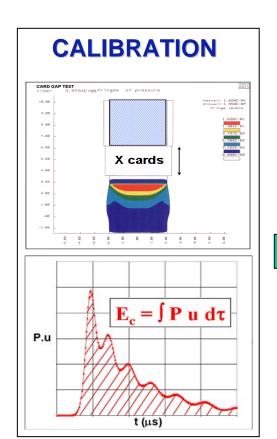
RAPHOTALIP 1 V230 (Basic Control of Control



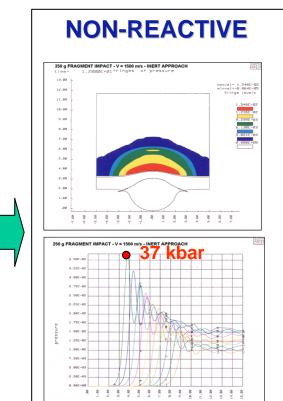


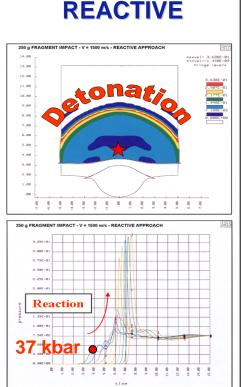


PRELIMINARY APPROACHES TO SDT



DGA/CAEPE



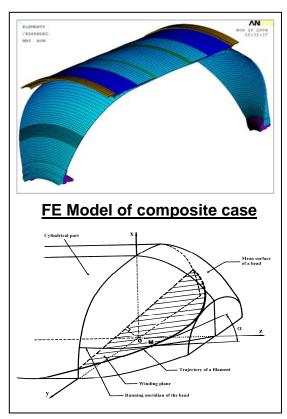


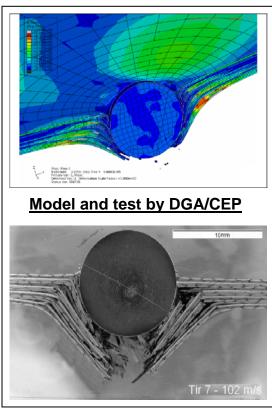


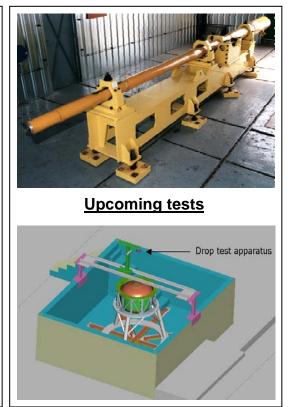




EXTENSION TO COMPOSITE STRUCTURES











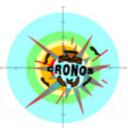


HAZARD AREAS PREDICTION TOOL IN CASE OF A SRM PNEUMATIC EXPLOSION Fragment projection, heat flux and air blast









dga.defense.gouv.fr

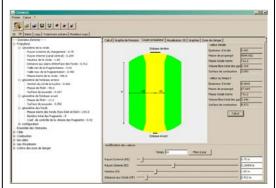






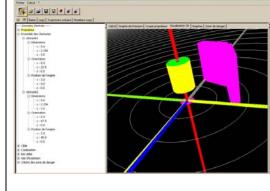
INPUT DATA

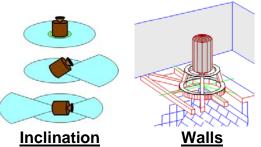
MOTOR



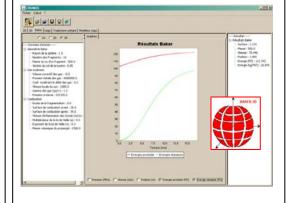
- SRM geometry
- Combustion gases
- Inert masses
- Chamber pressure
- Casing failure pressure

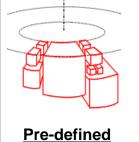
CONFIGURATION





FRAGMENTATION







<u>Modeller</u>

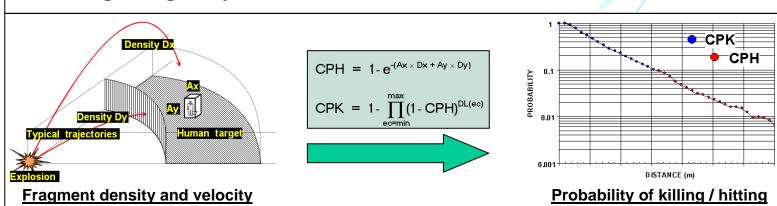




COMPUTATION

Fragment trajectory computed as a result of:

- Internal energy prior to casing burst
- Energy released after burst
- Drag and gravity forces



Also computed:

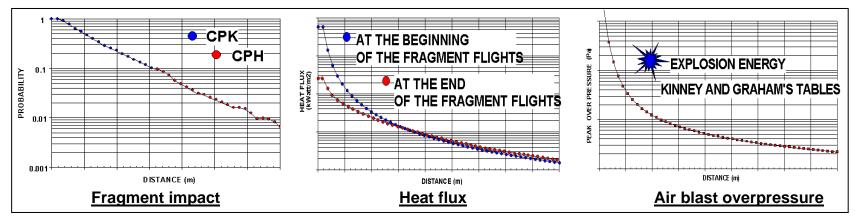
- Heat flux (after explosion and after the flight of all fragments)
- Air blast overpressure (by means of Kinney-Graham's tables)







RESULTS





	Area	Projection	Heat Flux	Air blast
	Z1	CPK > 0.5	(F/S) > 16	∆p > 0.43
	Z2	CPK > 0.1	(F/S) > 8	∆p > 0.2
	Z3	CPH > 0.03	(F/S) > 5	∆p > 0.14
	Z4	CPH > 0.01	(F/S) > 3	∆p > 0.05
	Z5	< max range	none (*)	∆p > 0.02

Criteria for safety assessment



Map and safety distances

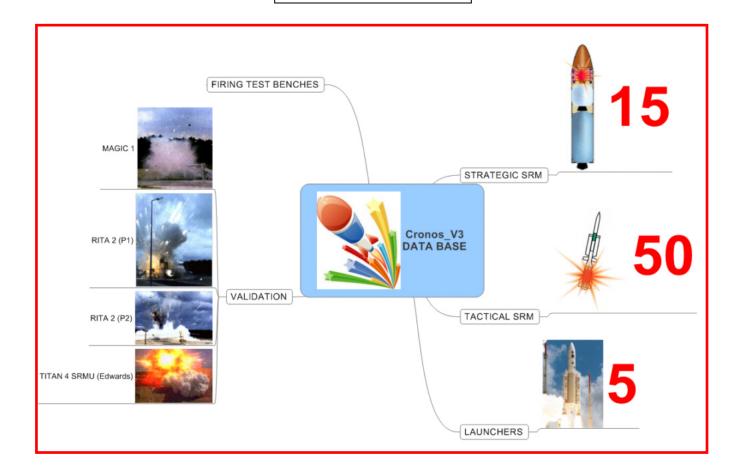






DGA/CAEPE

DATABASE









Nicolas COURONEAU

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MINISTÈRE DE LA DÉFENSE

New IM issue on naval platforms: Solid Rocket Motor (SRM) pneumatic explosion risk. Effects prediction methodology

French MoD: N.Duval, E.Faucher, Y.Garcia

2009 Insensitive Munitions and Energetic Materials Technology Symposium Tucson, Arizona May 11-14



DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

DGA and CAEPE

- DGA = Armament Procurement Agency of the French MoD DGA missions:
 - Preparing the future of defence systems
 - Equipping the armed forces
 - Promoting defence equipment export
- DGA operates its own test centres for "Testing" evaluating materials"

CAEPE is the DGA Propulsion Testing and Missile Safety

centre

- Located near Bordeaux
- 330 people
- 10 ground testing facilities
- 3000 ha
- 2000 tests carried out in 35 years





AL De REUIL

CAEPE: DGA Propulsion Testing and Missile Safety centre

- Our missions:
 - Testing and expertise:
 - Performance of propulsion systems for either strategic or tactical missiles
 - Ageing of propulsion systems
 - Safety assessment for propulsion system, ammunition and complete weapon system
 - Contractors support:
 - Assembling of propulsive stages for the French ballistic missiles
- Safety assessment:
 - Safety testing areas: all IM tests
 - Expertise division: simulations, technical support, IM tests interpretation





Slide N°3 / 20

Introduction: Solid Rocket Motor explosion, The new risk of naval safety studies

- IM munitions suppress mass detonation risk
- Naval hazard analysis highlight a new risk considering the high density of ammunition on board:
 - **Solid Rocket Motor explosion risk**
- Consequences of the risk: catastrophic (death of personnel, loss of the ship if sympathetic reactions)
- Different causes of explosion:
 - at ignition
 - during firing
 - due to accidental or combat threats
- Accurate assessment of explosion consequences necessary to:
 - Mitigate the risk
 - Meet system requirements





Introduction: Solid Rocket Motor explosion, The new risk of naval safety studies

- Specific configuration: SRM explosion in Vertical Launch System: SRM ignition in the ship → explosion in the VLS magazine
- Two main issues:
 - Sympathetic reaction?
 - Ammunition reaction scenario
 - Ship integrity threatened?
 - Thermal and pressure loadings



- Development of a new methodology based on simulations to deal with this ship confined configuration.
- Explosion effects divided and studied in 3 steps:
 - Fragments projection
 - II. Blast overpressure
 - III. Fire due to scattering of burning propellant fragments





I. Fragment projections

Study of fragment impacts on adjacent munitions and risk of initiation associated

Fragmentation computed thanks to CRONOS (in-house analytical code)



CRONOS: designed to delimit hazard areas generated by SRM explosion. Calculates:

Fragment size distribution
Initial velocities
Flight trajectories

Probabilities of hitting or killing
Heat fluxes

Air blast overpressure

5 hazard areas

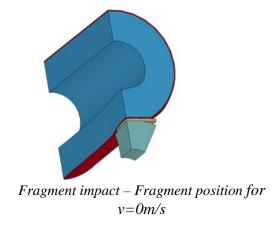
 CRONOS used in our study to determine fragment size distribution and evaluate initial velocities





I. Fragment projections

- CRONOS fragmentation: input of Ls-Dyna code study to predict initiation risk
- Fragment impacts directly adjacent missile

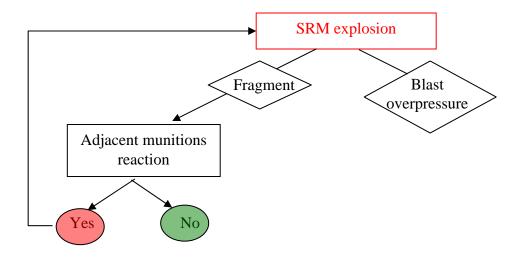


Conclusion on initiation: casing perforation or energy criteria





Effects prediction methodology







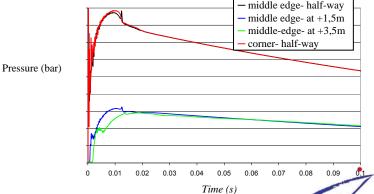
II. Blast overpressure effect Effect on donor canister

Study of blast effect on donor canister resistance

- Blast overpressure propagation simulated by CFD code Fluent
- Explosion modeled by a shock tube phenomenon: a pressurised hot gas volume released in its environment
- 3D model computes pressure loadings on the internal canister surface:

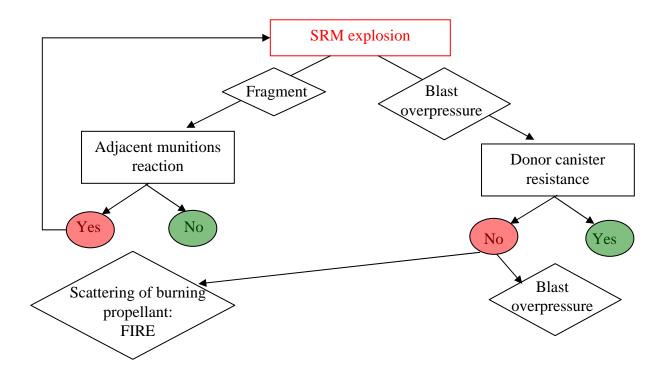
IMEMTS

- P0 = P_{structure failure}
- $\mathbf{V} = \mathbf{V}_{\text{free}}$
- Gas production amplified by the sudden enlargement of the combustion surface. This gas production is injected in the initial hot gas volume
- Conclusion on canister resistance: Comparison with canister failure value





Effects prediction methodology



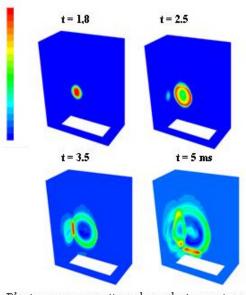




II. Blast overpressure effect Effect on VLS magazine and adjacent munitions

Study of the non-stationary pressure loadings on bulkheads and on adjacent canisters and determination of canister resistance

- 3D model of the magazine operated to model the pressure wave propagation
- Shock tube phenomenon:
 - Canister break-up effects are neglected
- Simulation computes time-dependent blast overpressure in every point in the magazine
- Important influence of the donor missile site in the magazine
- Conclusion:
 - Blast overpressure time-dependent mappings on bulkhead and adjacent canisters
 - Adjacent canister resistance: Comparison with canister failure value or Ls-Dyna simulation

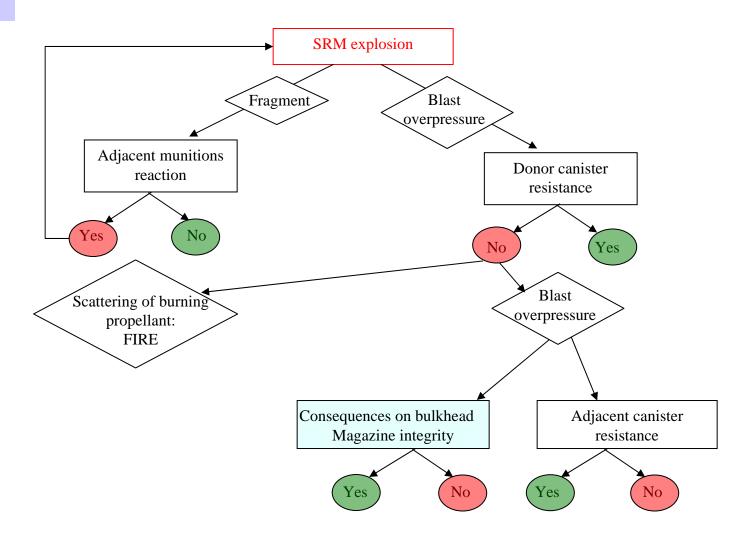


Blast overpressure time-dependent mappings on the magazine bulkheads



IMEMTS

Effects prediction methodology





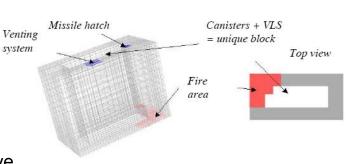


Slide N°12 / 20

III. Fire due to scattering of burning propellant fragments

Study of quasi-static pressure evolution and heat flux from propellant fire to canister and magazine bulkhead

- 3D model runs with Fluent, taking into consideration venting systems.
- Choice of Fluent: possibility to compute heat radiation and to take into account sonic outflow by venting systems.
- Choice of 3D model: necessity to identify local maxima of heat transfer (important for adjacent munitions initiation risk)
- Gas flow rate during fire determined thanks to CRONOS fragmentation combustion surface and pressure-dependent combustion velocity.
- Geometry considered:
 - Fire area limited next to the exploded missile:
 overvalue of pressure and heat flux→ safety at stake
 - Simplified geometry to limit calculation time: gas do not flow between canister, exchange volume and surface reduced→ conservative





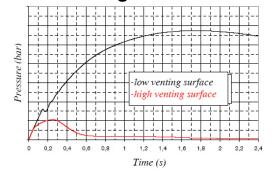




Results: Quasi-static pressure quickly uniform in the magazine

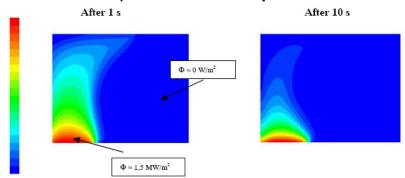
Quasi-static pressure evolution:

Result shows efficiency of venting device



Heat flux mapping on bulkhead (shows 3D aspect of thermal

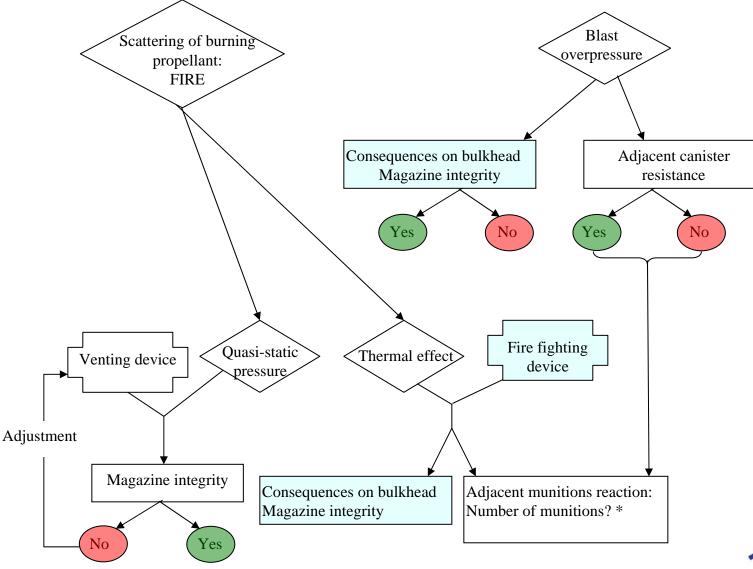
phenomenon):



- Conclusion:
 - Quasi-static pressure evolution: adequation of venting device implemented
 - Heat fluxes to determine bulkhead and adjacent missile temperature evolution



Effects prediction methodology







DGA/DE/CAEPE/EXP

IV. Adjacent missiles reaction risk evaluation

Study of adjacent missiles temperature evolution and reaction risk associated

- 1D model is used:
 - Conduction in canister
 - Radiation between canister and missile
 - Convection between air in canister and missile and canister walls
 - Conduction in different missile materials
- Inputs of 1D model: heat fluxes computed thanks to the 3D fire model
- Reaction missile criterion: reaching fast cook-of ignition temperature in the propellant.



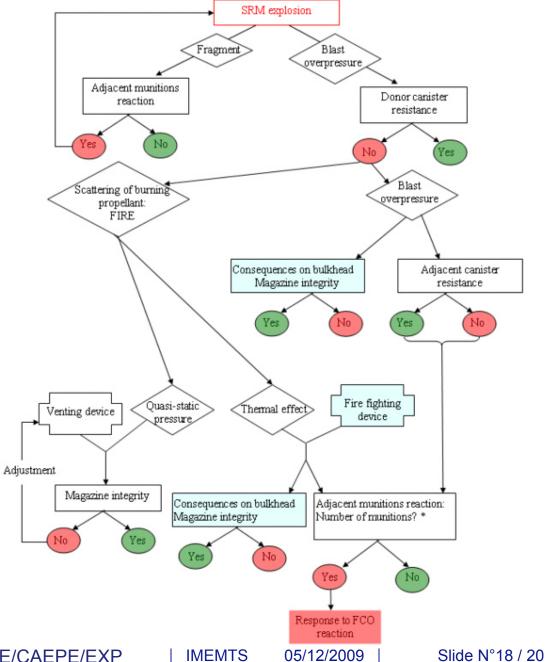


IV. Adjacent missiles reaction risk evaluation

- Outputs: adjacent missile ignition delay. Real difference between immediately adjacent munitions and others.
- To state on sympathetic reaction risk: comparison between ignition delay and fire fighting device initiation delay, taking into account its efficiency.
- If adjacent munitions reaction acknowledge, FCO SRM response: new missile reaction.
- Conclusion: construction of the whole reaction missile scenario.











Conclusion

- Methodology explores the large range of SRM explosion effects.
- Tackles the 3 types of threats associated to SRM explosion:
 - Mechanical threats:
 - Fragment projection
 - Blast overpressure
 - Thermal threats:
 - Fragment burning
- Use of CFD code: relevant choice for this confined magazine configuration. Good approach of blast wave with reflection phenomenon and thermal effects with local maxima identification
- Study outputs various:
 - To assess reaction risk of adjacent munitions. Whole reaction scenario in VLS magazine consequently to SRM donor explosion can be drawn up
 - To assess VLS magazine and ship integrity. The on-board consequences: object of another study conducted by CTSN (DGA centre)

The methodology provides strong elements to achieve an accurate assessment of the safety level of VLS integrated on board.



Any questions?

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Modeling Fragmentation Performance of Insensitive Explosive Fragmentation Munitions

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



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Mr. P. J. Samuels

Mr. L. Sotsky

Mr. T. Wu

Polytechnic Institute of New York:

Professor L. I. Stiel

Outline



- Introduction: Overview of the PAFRAG (Picatinny Arsenal FRAGmentation)
 Modeling Methodology
- Modeling Fragmentation Performance of Insensitive Explosive Fragmentation Munitions
- Summary



PAFRAG Modeling Methodology



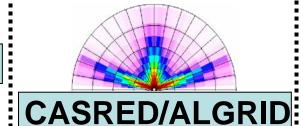
Expensive

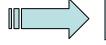
Fragmentation Arena Testing





Z-data





CALE



PAFRAG



Lethality Modeling



Inexpensive

CALE

Dynamic high-strain high strain rate continuum analyses

PAFRAG – Picatinny Arsenal Fragmentation code

Fragmentation modeling

CASRED/ALGRID

Lethality Codes

Model the effectiveness of the munition

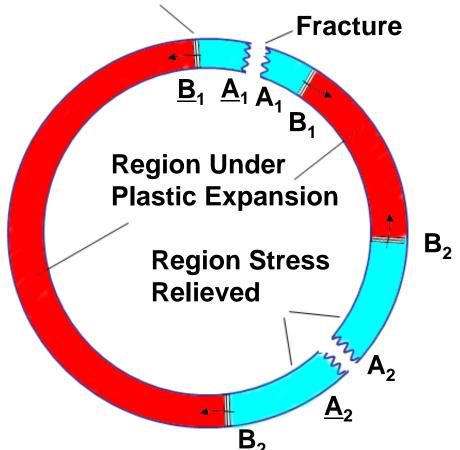


Natural Fragmentation: PAFRAG-MOTT Model



Based on Mott's theory of break-up of cylindrical "ring-bombs"

Stress Release Wave



γ is a statistical parameter and can be determined from fragmentation test data

Average circumferential fragment length:

$$x_0 = \left(\frac{2P_F}{\rho\gamma}\right)^{1/2} \frac{r}{V}$$

Average fragment mass:

$$\mu = \frac{1}{2} \rho x_0^3$$

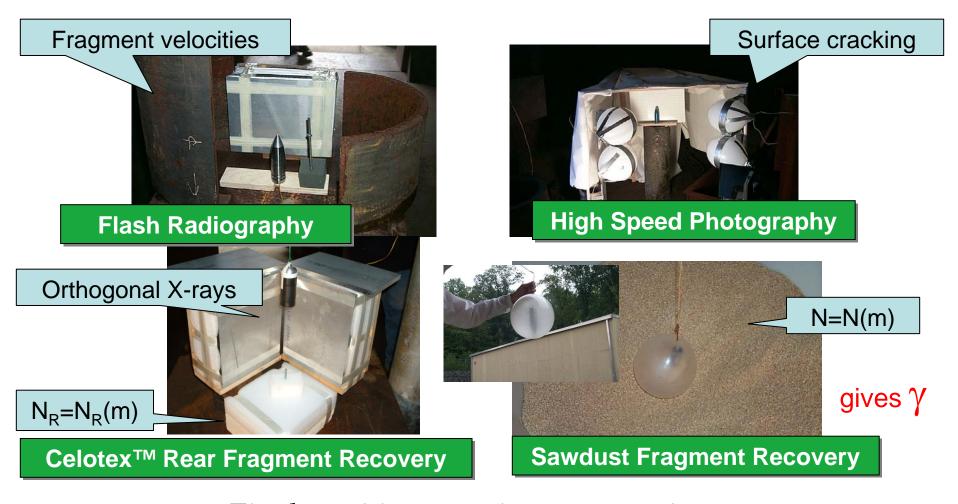
Fragment size distribution:

$$N(m) = N_0 e^{-\left(\frac{m}{\mu}\right)^{1/2}}$$



PAFRAG Experimentation





Final munitions require arena testing

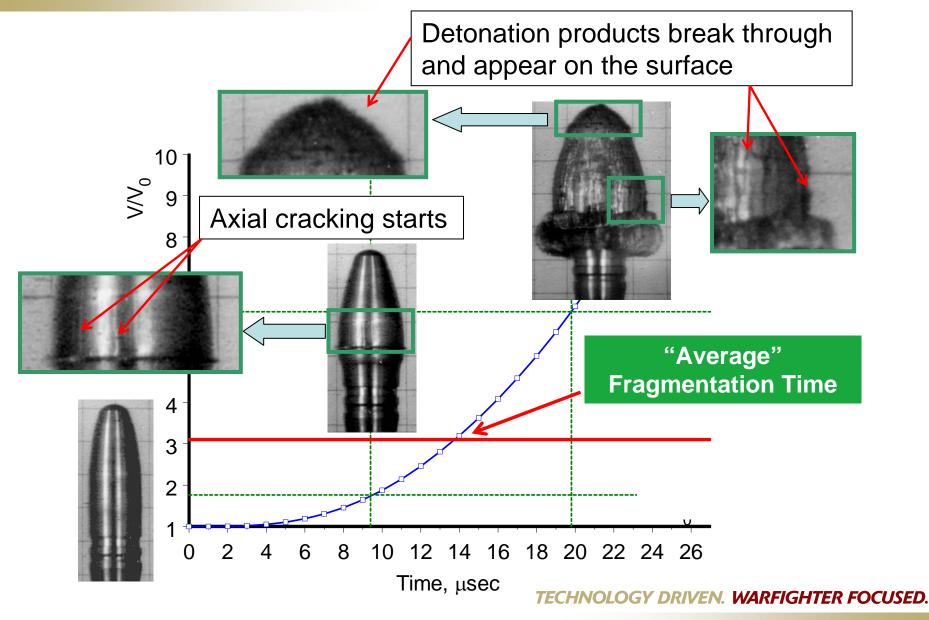
PAFRAG experimentation is adjusted according to specific project/customer needs

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V/V_o vs Time and High Speed Photography

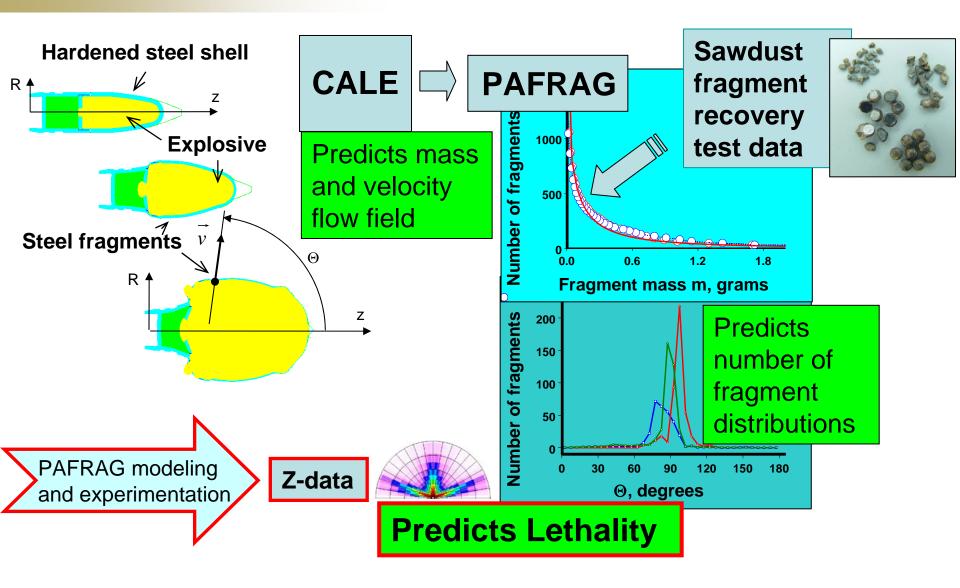






PAFRAG Modeling Methodology for Lethality Assessments

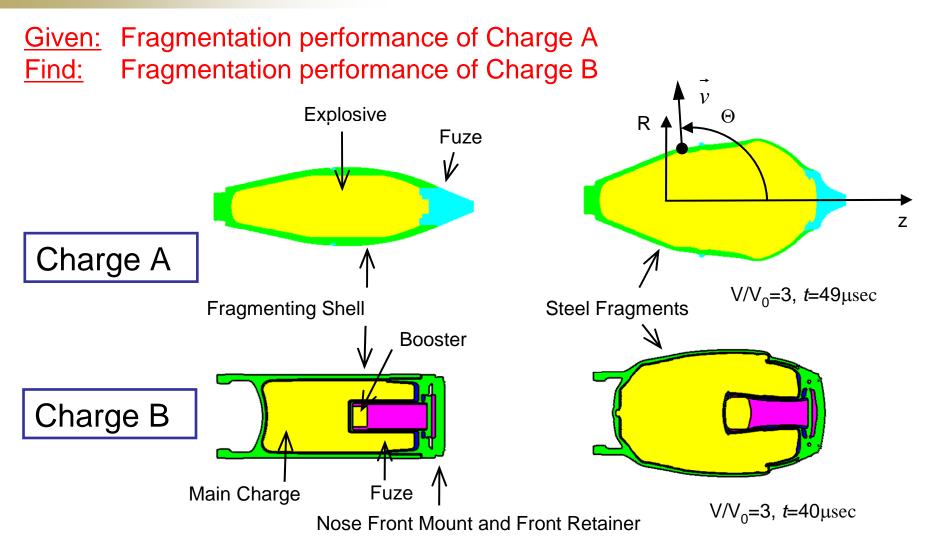






CALE-PAFRAG Modeling

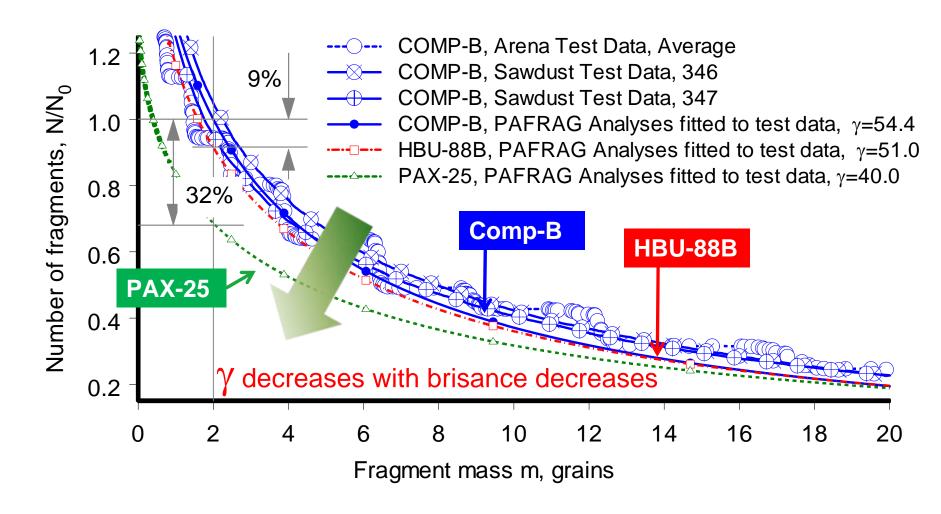






Cumulative number of fragments versus fragment mass, Charge A

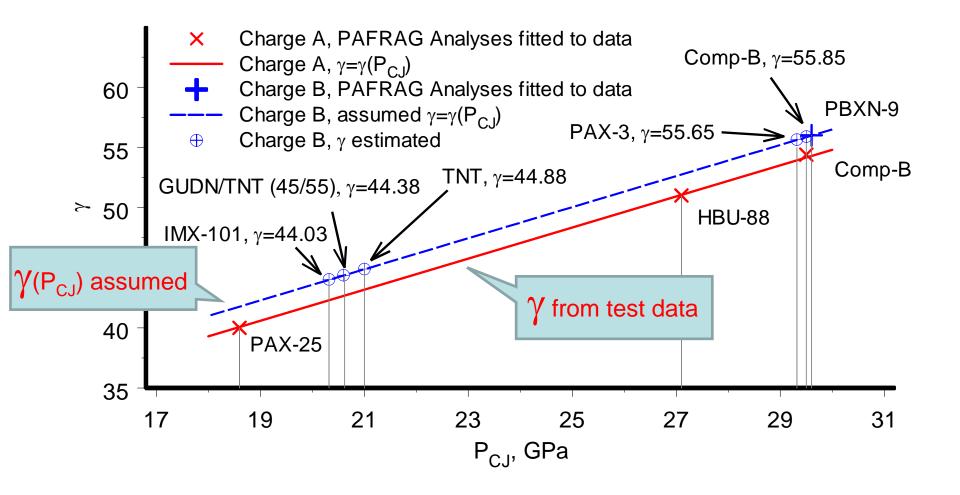






Parameter γ versus explosive detonation Chapman-Jouguet (CJ) pressure

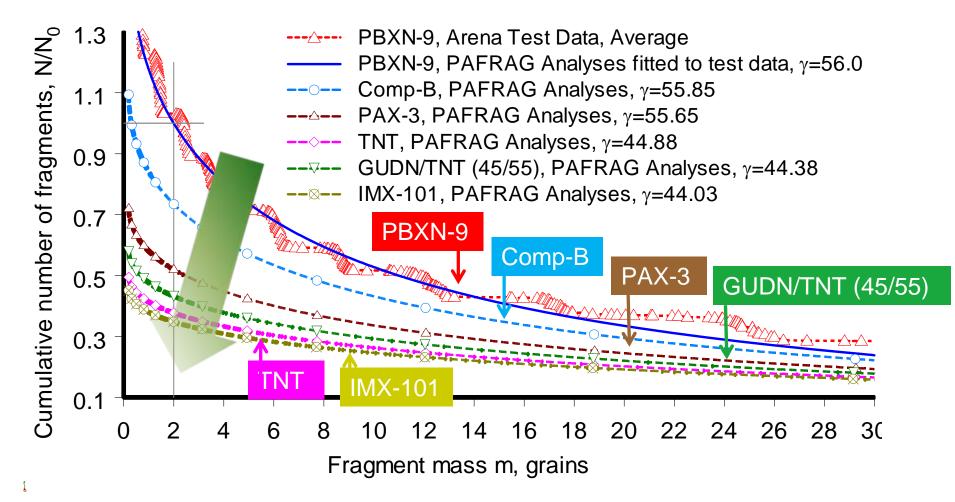






Cumulative number of fragments versus fragment mass, Charge B





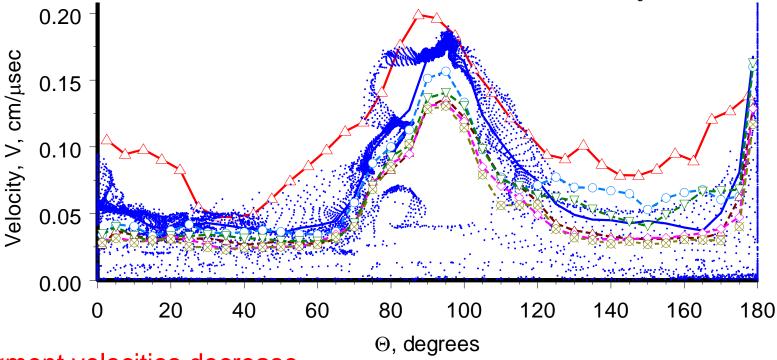
 P_{CJ} decreases, γ decreases, fragmentation performance degrades



Fragment velocities versus theta for varying explosive compositions, Charge B



- PBXN-9, Arena Test Data
- PBXN-9, PAFRAG Analyses, Cell Data, t=40μsec, V/V₀=3
- PBXN-9, PAFRAG Analyses, Momentum Average, t=40μsec, V/V₀=3
- Comp-B, PAFRAG Analyses, Momentum Average, t=45μsec, V/V₀=3
- → PAX-3, PAFRAG Analyses, Momentum Average, t=48μsec, V/V₀=3
- TNT, PAFRAG Analyses, Momentum Average, t=52μsec, V/V₀=3
- --- GUDN/TNT (45/55), PAFRAG Analyses, Momentum Average, t=49μsec, V/V₀=3



Fragment velocities decrease



Summary



- ✓ New modeling methodology for assessing performance of IM munitions developed
- ✓ Employing IM explosives with low brisance properties and low Chapman-Jouguet (CJ) pressures leads to decreases in the fragment numbers and velocities
- \checkmark Based on the experimental data available to-date, an approximately linear relationship between the γ -parameter and the Chapman-Jouguet (CJ) detonation pressures is observed
- ✓ To maintain lethality requirements, explosive fragmentation munitions with IM formulations requires employing high fragmentation steel alloys, or controlled/preformed fragmentation techniques, or a combination of thereof





Questions?





Back-up slides





Synthesis and Process Development of NONA

Dr. David Price

BAE Systems/HSAAP

May 2009

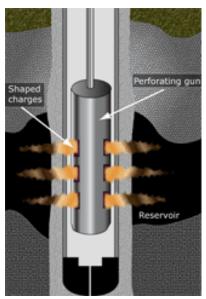






Background

- NONA (2,2',2",4,4',4",6,6',6"-Nonanitro-m-terphenyl) is:
 - a highly thermally stable explosive (Mp > 400°C)
 - an easily detonable explosive
- Originally developed by NOL for space applications in 1960's
 - Mostly to succeed HNS (Mp = 316°C) and DIPAM (Mp = 305°C)
- Used in Exploding Foil Initiators (EFIs), boosters, shaped charges, etc. in commercial downhole wells for oil and gas industry



$$O_2N$$
 O_2
 O_2







Thermal Stability Evaluations

NONA is much more thermally

stable than TATB

At temperatures higher than 200C, NONA is more thermally stable than HNS

200°C TEMPERATURE VACUUM STABILITY TESTS

Material	2	7	14 Total	21 gas e	Time 28 volved	e of e 35 (cm ³ /	xposure 42 g at STI	49	ys) 56 Average	63 of tw	70 o samp	77 les.)	84	91
ABH A BTX bis-hnab	.9	2.4 .9 18.4	4.7 1.5	7.9 2.0	12.9	19.5 3.1	3.9	5.0	6.2	7.7	9.9	12.0	14.6	17.6
DATB° DIPAM ^d DODECA DPBT°	2.8 2.5 .9	3.6 3.3 1.4 2.2	4.5 4.2 1.9	5.5 5.0 2.4	6.2 5.9 2.9	7.4 6.9 3.5	8.4 7.9 4.2	9.5 9.4 6.3	10.4	11.8 11.7 7.7	13.2 12.8 8.0	14.7 14.2 8.4	16.4 15.6 9.0	9.7
DPPM HNAB ^f HNBP	.7 .4 .6	1.5 2.0 1.5	4.4 2.0 9.8 2.2	6.8 2.7 27.8 3.0	9.0 4.0 3.6	12.3	15.0 6.6 4.8	7.7 6.8		9.6	10.3	10.8	11.6	12.8
KHN D¤ HN S HN DS¤	2.4 .4 .7	15.0 .7 1.3	1.0	1.2	1.4	1.6	1.7	1.8		2.3	2.5	9.8 2.6	2.8	3.0
NONA ONT PADP I ¹	.4 .9 15.0	1.3	1.1	1.6	2.0 1.6	2.3 1.7	2.8 1.9	3.2 1.9		3.9	4.3	4.7 2.4	5.1 2.5	5.4 2.6
PATO PENCO PYX TATB ¹ TATB ^k	1.0 .1 .1 .3	1.9 .2 .1 .9	2.8 .3 .2 2.1 12.5	3.4 .4 .2 4.1 20.0	4.0 .6 .2 7.2	4.6 .6 .3 11.1	5.2 .6 .3 15.8	5.6 .7 .4		6.5	7.2 1.0 .5	7.7 1.1 .6	8.7 1.2 .6	10.7
TNN TPB TPM ¹	.3 .1 .8	.5 .1 4.2	.6 .2 7.7	.8 .3 11.7	.9 .3 15.6	1.0	1.2 .3	1.3		1.6	1.7	1.8 3.2	2.0 7.0	2.2 9.5
TPT T-TACOT Z-TACOT	. 1	.5	. 4	1.3 .8	1.6 1.0	1.9 4.1	.5 2.1 4.9	2.5 7.1	3.0	.7 3.5 10.8	.9 3.9 11.2	1.0 4.3 11.4	1.0 4.8 11.5	1.1 5.3 11.5

[&]quot;ABH terminated after 35 days." bis-HNAB aborted after 6 days.
DATB terminated after 82 days.

d DIPAM terminated after 86 days.

DPBT terminated after 42 days.

HNDS aborted after 5 days, evolved gas blew mercury into catch basin between 3 and 5 days.

KHND terminated after 30 days.

1 PADP-I aborted at 2 days, evolved gas blew mercury into catch basin in less than 2 days.

TATB terminated after 42 days.

J. F. Baytos, "High-Temperature Vacuum Thermal Stability Tests of Explosives," LA-5829-MS, Los Alamos National Laboratory, January 1975.





Performance

- NONA has similar explosive performance to Tetryl
- Better performance than HNS and TACOT (other thermally stable EMs)

Compound	Melting Point (C)	Density (g/cm3)	P _{c-j} (kbar)	Detonation Velocity (m/s)
NONA ¹	440	1.78	255	7570 (calc)
Tetryl ²	130	1.71	260	7850
TACOT ²	378	1.61	181	6530
HNS ²	316	1.60	200	6800

 ¹ Hamid, J.; Griffiths, T.; Claridge, R.; Jordan, T. "Application of Novel Energetic Materials for Initiators and Explosive Trains", New Trends Res. Energ. Mater. Proc. Sem, 2004, 133-141

 ² Cooper, P.W.; Kurowski, S.R. "Introduction to the Technology of Explosives" Wiley-VCH, 1996

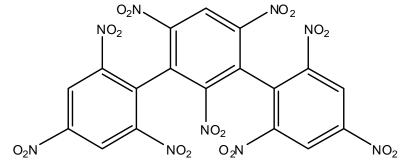


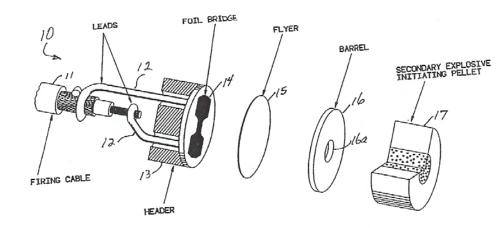


Sensitivity

- NONA has impact sensitivity characteristics between PETN and RDX.
- NONA has impact and friction sensitivity similar to Tetryl.

Compound	Impact Sensitivity (cm)	BAM Friction Sensitivity (N)
NONA	20-25	300
RDX	32	120
PETN	17	60
Tetryl	26	350





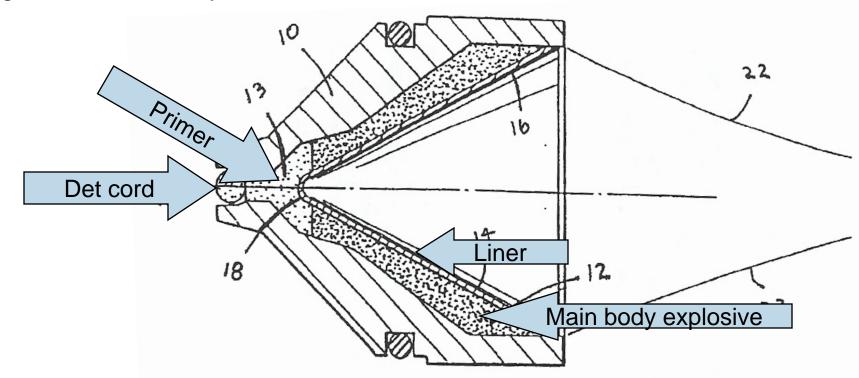
• EFI image: Barker, J.M. "Exploding foil initiator using a thermally stable secondary explosive" U.S. Patent #5,431,104, 2002.





NONA uses

- Shaped charges for downhole well applications (oil and gas industry)
- •NONA can be used in the primer and/or the main body explosive due to its high thermal stability and its ease of initiation.



 Yang, W. et al "High Temperature Explosives for Downhole Well Applications" U.S. Patent Application Publication # US 2002/0129940 A1, 2002.





Program Objectives

- Develop a process that can produce 1-2 lbs/month of NONA in HSAAP lab facilities
- Develop a process that can be scaled to produce a minimum of 10-20 lbs/month of NONA with minimal infrastructure cost to OSI
- Keep cost competitive!









Original NONA synthesis

- Picryl chloride and styphnyl bromide are made through harsh nitrations
- Recrystallizations required
- Final step consists of Ullmann coupling in inert solvent(s) at high temperatures.
- Patent method # 3,755,471
 (Dacons, 1973)

$$\frac{\text{KNO}_3, \text{SO}_3 \text{ in H}_2\text{SO}_4}{70\% \text{ yield}}$$
 $\frac{\text{NO}_2}{\text{Br}}$
 $\frac{\text{KNO}_3}{\text{NO}_2}$

SB

 $\begin{array}{c} \textbf{NONA} \\ C_{18}H_5N_9O_{18} \\ \textbf{Mol. Wt.: 635.28} \end{array}$





Modified NONA Synthesis

 Sitzmann, M.E. "Method for making nonanitroterphenyl" U.S. Patent # 6,476,280 B1, 2002.

$$O_2N$$
 O_2N
 O_2N

- Styphnyl chloride is homocoupled in Ullmann coupling to produce di-halo-NONA (and biphenyl and quaterphenyl, etc).
- O_2N NO_2 NO_2 NO_2 NO_2 NO_2 NO_2 NO_2 NO_2 NO_2

NONA

- Resulting material is dehalogenated in final step with iodide source under acidic conditions.
- Terphenyl material can be isolated before or after last step.
- Advantage: only one organic starting material required.





Progress

- We have synthesized NONA by the conventional route.
- We now have (and are using) a novel route to produce NONA.
- We are also exploring other, more novel routes to make NONA.



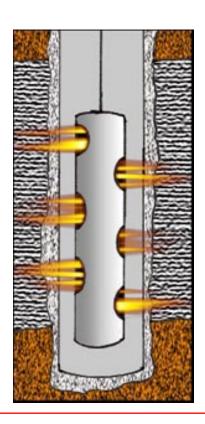






Novel Route Highlights

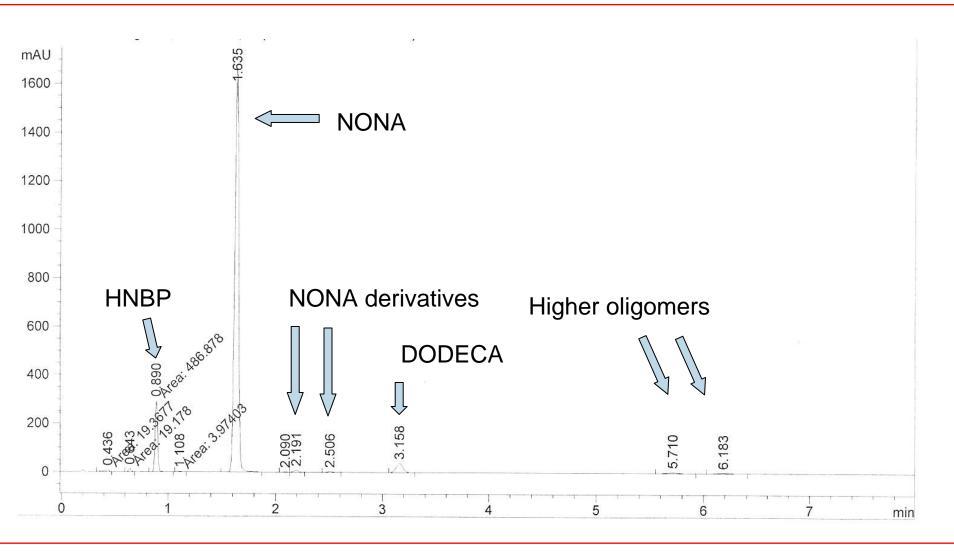
- Lower temperatures required for entire synthetic route
- Scalable on Holston's infrastructure
- Simpler purification
 - Less solvents (and corresponding waste)
 - Fewer steps
 - Less labor intensive
- Higher yielding route
 - Our yield increased >75%
- Competitive cost







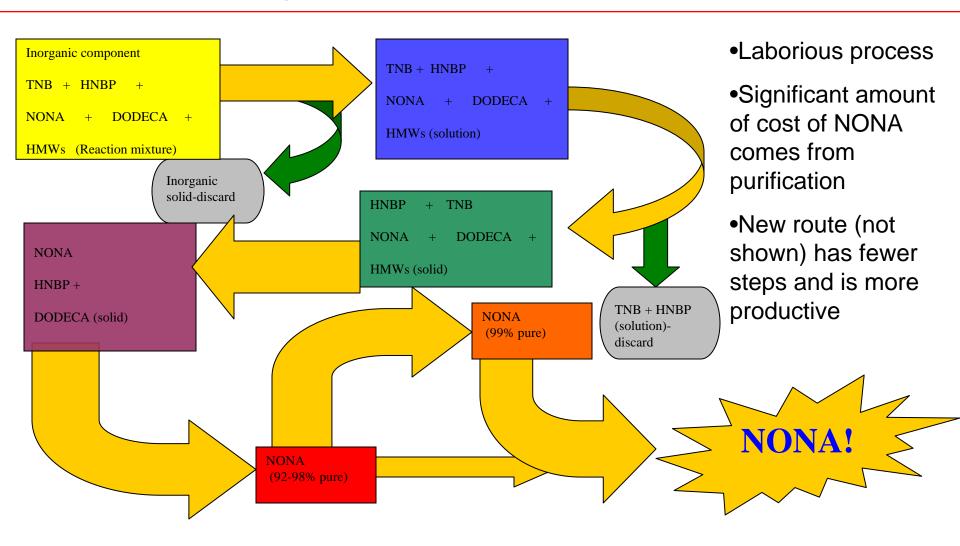
Crude NONA-HPLC analysis







Purification of NONA-old route

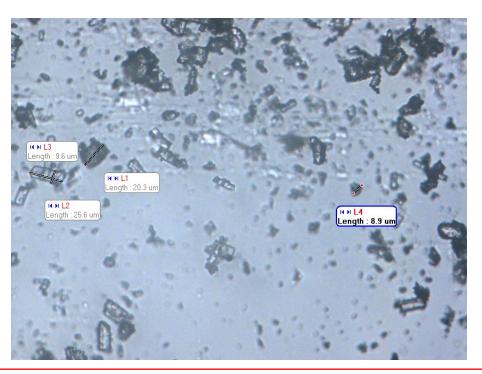


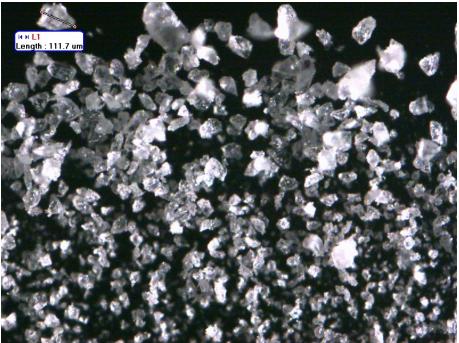




NONA Particle Size Modification

- Various solvent/antisolvent combinations were evaluated.
- Dissolution in hot solvent and addition of water or IPA affords 15-20 micron material.
- Addition of NONA solution to water or IPA affords <5 micron material.









Conclusions

- OSI's novel synthetic route to make NONA should be scalable with little infrastructure cost (still evaluating)
- We are currently producing 1-2 lbs/month of NONA
- We are planning to make larger quantities (10-20 lbs/month) in FY10
- We are also evaluating the manufacture and properties of DODECA, the 4-ring analog of NONA.

DODECA





Acknowledgments

- BAE Systems, HSAAP
 - Mr. Jean Fleischer (the <u>real</u> NONA maker)
 - Mr. Jim Owens
 - Mr. Jim Haynes
 - Ms. Kelly Guntrum
 - Mrs. Lisa Hale







Novel Manufacturing Process Development and Evaluation of the High Blast Explosive PAX-3 with BDNP A/F and R8002 Plasticizers

NDIA Insensitive Munitions & Energetic Materials Technology Symposium 2009



K.B. Yim U.S. Army RDECOM-ARDEC, Picatinny Arsenal





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- Matt Hathaway
- Kelly Guntrum





Enhanced Blast Explosives

- Deliver More Energy on Target than Traditional Explosives
- Types of Enhanced Blast Explosives
 - Metallized Explosives
 - Reactive Surround
 - Fuel Air
 - Thermobaric

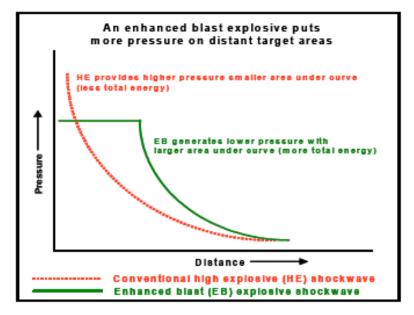


Fig. Comparison of conventional explosives and enhanced explosives.





Enhanced Blast Explosives

- Rely on Blast (Primary) and Heat (Secondary) for their Effects
- Effects Intensified in Confined Spaces (Buildings, Bunkers, Caves, Vehicles, etc.)
- Active Elements are an Explosive and a Fuel (metal)
- Vacuum or Oxygen Depletion Effect is Achieved







PAX-3

- Developed by ARDEC Under the Novel Energetics Science and Technology Objective (STO)
- Evaluation for the M141 Bunker Defeat Munition
- Evaluation for Line of Sight Multi-Purpose (LOS-MP)











PAX-3

- PAX-3
 - HMX
 - Cellulose Acetate Butyrate (CAB)
 - BDNPA/F plasticizer
 - Aluminum
- Replacement for Aluminized Comp. A-3







Concrete wall 10' wide, 10' tall 8" thick, reinforced with double steel rebar





PAX-3 INSENSITIVE MUNITION TESTING

PAX-3 3.2" Generic Shaped Charge IM Test Summary*						
IM Test	# of Tests	Reaction				
Bullet Impact	2	Pass No Reaction				
(50 cal 2800 ft/s)		Pass No Reaction				
Army Fragment Impact (Cube 6000 ft/s)	2	Pass Burn				
		Pass Burn				
Slow Cook Off (50 F /hr)	2	Fail Explosion/Deflagration** Fail Explosion/Deflagration**				
Fast Cook Off	2	Pass Burn Pass Burn				

^{*} Initial Assessment

^{* *} This reaction can be potentially mitigated by adequately venting the warhead

PAX-3 SENSITIVITY AND PERFORMANCE TEST DATA						
	PAX-3	Al Comp A3	LX-14			
Impact (cm)(50%)	39.5	80.4	26			
LSGT (50%)	129.5	119+/- 3	199			
Detonation Velocity (m/sec)	8070	8199	8680			

Performance and sensitivity data provided by ARDEC

Data Originally Presented at 2006 IMEM



PAX-3 Current Processing

- HSAAP Slurry Processing
 - Explosive intermediates slurried in water
 - Polymer / Plasticizer dispersed in solvent
 - Coating / processing cycle
 - Recovery / reuse of solvent
- Traditional Method Incompatible with Thermobaric PBX
 - Aluminum powder readily oxidized by water
 - Safety issues significant at production-scale operations
- "Water Replacement" (WR) Fluid Evaluated *
 - Not reactive with metal powders
 - Fluidizing effect of water
 - Colorless, nonflammable liquid
 - Similar boiling point range as water
- Recovery of WR Fluid Key to Controlling Product Cost
- * Previously Reported in 2006 IMEM





PAX-3 Current Processing

Issues

- Water Replacement Fluid Expensive
- Separation of Water Replacement Fluid from Solvent Difficult
- Supplier Discontinued "WR" Fluid Currently Employed for Manufacture

New Solution

- Re-evaluate Traditional Aqueous Slurry Technology to Manufacture PAX-3
- Known Technology
- Minor Changes to Processing Technique
- Significant Cost Savings to the Customer





PAX-3 Aqueous Development

- Processing Concerns
 - Hydrogen Gas Generation During Coating Cycle
 - Time / Temperature of Aluminum Exposure in Slurry
 - pH of the Slurry Medium
- Material Evaluation
 - Explore any "Additives" that has the Potential to Impede or Delay Gas Generation





PAX-3 Aqueous Process Development

- Lab-Scale Process Development
 - Design of Experiments
 - Baseline Using "WR" Parameters
 - Systematic Evaluation of Process Parameters for PAX-3
 - Time
 - Temperature
 - Agitation
 - Addition Rates
 - Process "Additives"
 - Typical lab batch size of 1,000 grams
 - 2 "Additives" Identified and Employed for Processing
 - Gas Generation Monitored Real Time
 - H2 Scan: HY-Optima 1720 Process Monitor

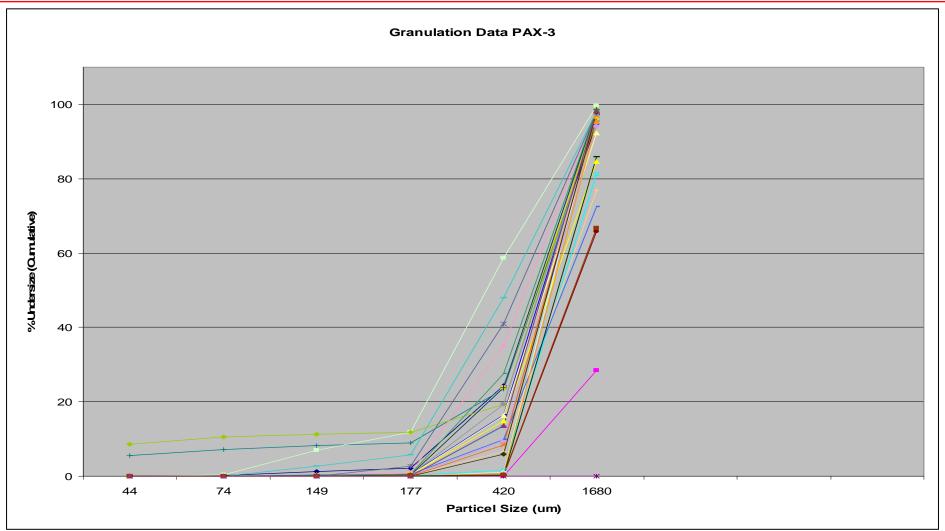


10 L Coating Still





PAX-3 Laboratory Granulation





Process Development Conclusion

- Key Variables
 - Time
 - Resonance Time Coating Process
 - Solvent Concentration
 - Very Tight Tolerance
 - No Growth of Granules
 - Excessive, Rapid Growth into Agglomerations-Undesired Product
- Hydrogen Gas
 - Negligible Level Detected at Lab Scale Evaluation
- Production Scale Batch
 - FMEA Completed
 - Industrial Hydrogen Gas Detector Purchased/Commissioned
 - Process Parameters Established Based on Lab Scale Development Efforts
 - 2 x 500 lb Batches Scheduled for Week of April 27th







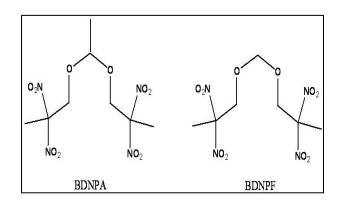
Plasticizers

BDNP A/F

- Energetic Plasticizer
 - 50% bis(2,2-dinitropropyl)acetal (BDNPA)
 - 50% bis(2,2-dinitropropyl) formal (BDNPF)
- Initially Developed in 1950's for Polaris Program
- First Manufactured by U.S. Navy (Indian Head) and Aerojet in the 1960's
- Later Manufactured by Thiokol in the 1990's
- Used Today in Various Formulations
 - LOVA Propellants
 - Navy PBX 106 Formulation
 - IM Explosives (PBXN-106, PAX-2A and PAX-3)

R8002

- 50% Dinitroethylbenzene (DNEB)
- 50% Trinitroethylbenzene (TNEB)
- Similar to K10 (65:35 DNEB:TNEB)
- Used Internationally as an Energetic Plasticizer in Experimental Applications







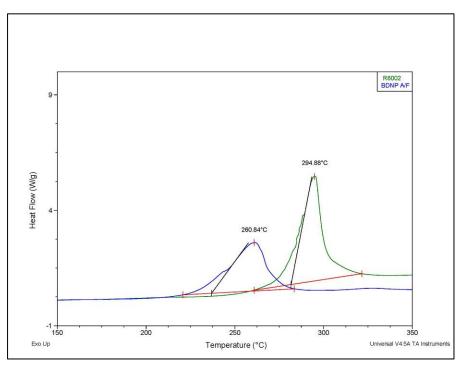
PAX-3 w/ R8002

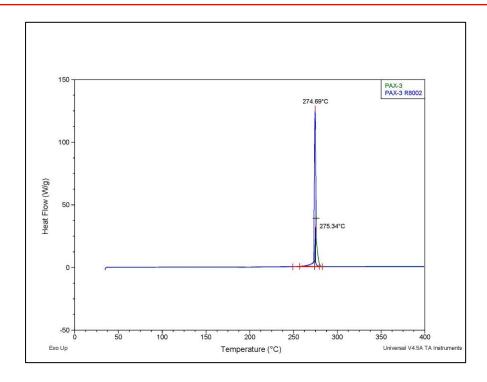
- Processing
 - Drop in Replacement with Current Aqueous Procedure
 - No Observable Change in Processing Steps
- Observations
 - Binder Lacquer system is less viscous than BDNP A/F
 - Binder Components Readily Mix with Little Mechanical Input
 - PAX-3 Product Using R8002 Generates a Higher Bulk Density Under Same Process Conditions
 - No Compatibility Issues





DSC Analysis





Plasticizers
BDNP A/F vs. R8002
Ramp 5°C/min

PAX-3
BDNP A/F vs. R8002
Ramp 5°C/min





PAX-3 Analysis

Batch #	PAX-3 Plasticizer	DSC Exothermic Peak °C	VTS Evolved Gas g/cc	Press Density	ERL Impact cm
1069-88C	BDNP A/F	275.34	0.266	1.73	36.14
1069-114	R8002	274.69	0.132	1.80	41.40





Conclusion

- The Aqueous Coating Method Provides Spec. Product
- Method Conforms to HSAAP Infrastructure
 - No Specialized Pumps, Seal, or Handling Equipment as with "WR" Method
- Product to Be Scaled to 500 lb Batch Size for Pilot Production Trial
- The R8002 Plasticizer Showed No Processing or Compatibility Concerns
 - Drop in Replacement for BDNPA/F





IT ALL STARTS HERE!!





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Innovation ... Delivered.

The Incorporation of New Refining Technologies Within the Existing Nitrocellulose Manufacturing Process at the Radford Army Ammunition Plant

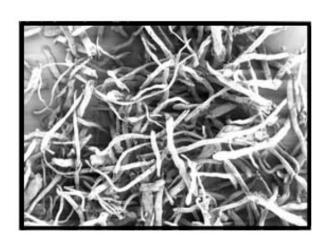
Zachary Higginbotham May 12, 2009



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Discovered in the mid-1800's

- First synthesized by Schönbein, highly unstable
- Abel perfected the purification process allowing "safe" manufacture
 - First Application: Black powder replacement
 - Celluloid photographic film, table tennis balls, knife handles, fountain pens



Current Applications

- All extruded gun and small rocket propellant products across entire DoD
 - Flake and spherical powders in small caliber
 - Granular propellant in medium and large caliber (direct and indirect fire)
 - Extruded rocket motors (MK-90 Hydra 70mm, M7-TOW/SMAW, Javelin)

RFAAP is the Sole NC Manufacturing Plant in North America

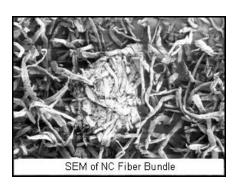
Nitrocellulose Refining Improvement



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Problem Statement:

 Nitrocellulose (NC) fiber quality influences propellant processing/performance as well as final product ballistic properties and contributes to undesired weapon system variability.



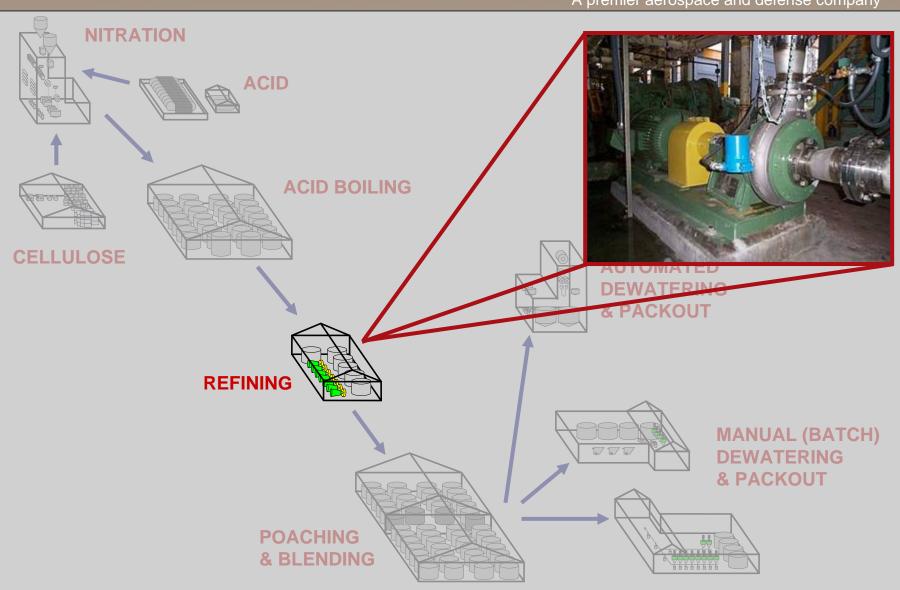
Objective:

- Develop a process to improve fiber quality (fiber length, distribution, residual agglomerates) within the existing refining operation
 - Incorporate learnings from similar industries to "push the envelop" of NC manufacturing technology
 - Maintain existing refining process cycle time

NC Manufacturing Process Flow at RFAAP



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What is Fiber Quality?



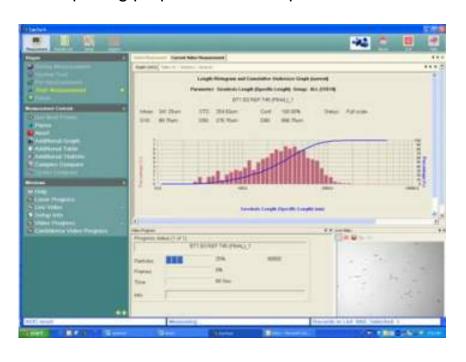
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Fiber Quality:

- Describes the relative dispersion of fibers and agglomerates during NC manufacture
- Fiber bundles are remnant unrefined particles due to an inefficient/ineffective refining process.
 - Artifact of sheeted cellulose and sheet opening/preparation technique



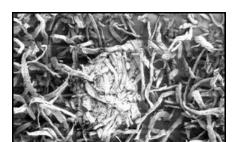




Goal: Achieve customer desired fiber length with minimum bundles

Results Are Evident In Product Quality Improvement ATK

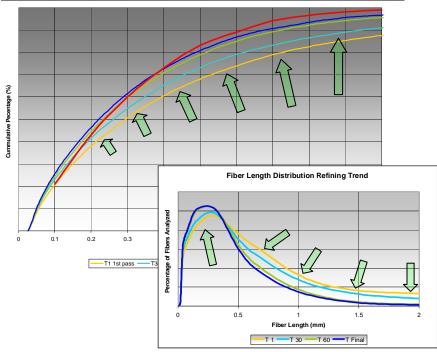
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SEM of NC Fiber Bundle



Improved NC Fiber Quality



Results:

- Real-time fiber analysis developed characterizing processing effects
- Deflakers provide free fibers from NC with multiple cellulose sources
 - Minimizes residual agglomerates (fiber bundles)
- New process controls optimize and control to target requirements

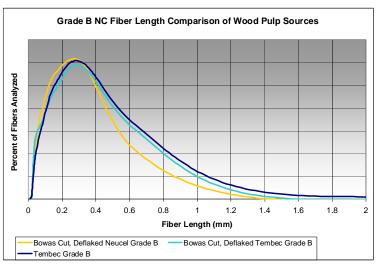


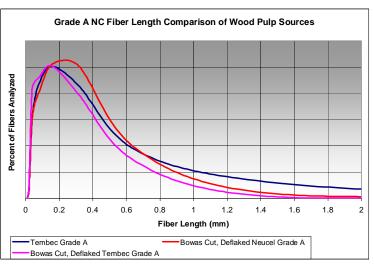
Deflaked NC Fiber Quality Characterized

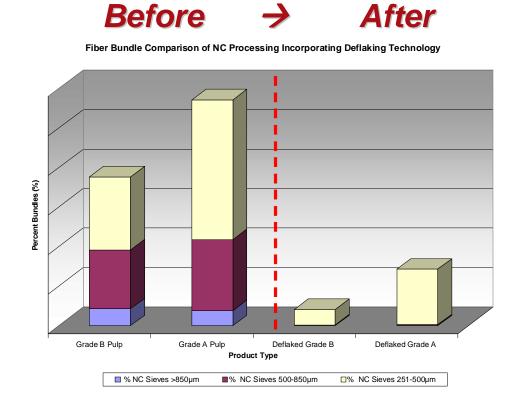


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• New processing methods maintain long fiber lengths, narrows fiber distribution, and minimizes bundles







Significant Improvements in Fiber Quality Realized

Results and Conclusions Driven by Data



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Successful Incorporation of New Pilot Equipment

- Deflaking technology proven in NC manufacture
 - Adapted from recycled fiber market segment

Improved NC quality from sheeted cellulose

- Single base propellant manufacturer qualified on new process
- Improved process robustness and product attributes towards cellulose source

Where Next?

- Currently executing a US government process improvement program installing full sized deflaking process at RFAAP
 - Leverage product quality improvement on entire NTIB NC base
 - Project to be complete summer of CY2009

Cutting Edge Process Improvement and Characterization



Acknowledgments



Thanks are due to the following individuals for their tireless support on this project.

- Mario Paquet Process Technology Manager, GD-Valleyfield
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- Jon Cloe Research Chemist, ATK Energetic Systems
- Jamie Allison NC Operations Manager, ATK Energetic Systems







DEVELOPMENT & OPTIMIZATION OF A PRODUCTION SCALE PROCESS FOR THE MANUFACTURE OF IMX-101 AT HSAAP

NDIA Insensitive Munitions & Energetic Materials Technology Symposium 2009



Virgil Fung *, Curtis Teague, Andrew Wilson BAE SYSTEMS OSI, Holston Army Ammunition Plant

Crane Robinson *, Paul Vinh RDECOM-ARDEC, Picatinny Arsenal







Briefing Outline

- Background
- Program Objectives
- Manufacturing Process Overview
- IMX-101 Producibility Phase 1
- IMX-101 Producibility Phase 2
- Conclusion











Acknowledgement

- PM-CAS
 - Mr. Charlie Patel
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 - Mr. Matt Hathaway
 - Mr. Ed LeClaire
 - Mr. Roger Williams
 - Mr. Brett Lifford
 - Mr. Jeff Dill
 - Ms. Donna Bowyers
 - Process Operators in Building L-4











Background

- IMX-101 Formulation
 - Developed at Holston Army Ammunition Plant (HSAAP) as a replacement of TNT
 - Contains non-traditional ingredients such as DNAN & NTO
 - Ingredients manufactured and/or processed at HSAAP
 - Superior IM performance than TNT in 155mm M795 projectiles
 - Passed all IM Engineering Tests (Bullet Impact, Fragment Impact, Slow Heating, Fast Heating, Sympathetic Reaction & 81mm Shaped Charge Jet Impact)
 - IM test results presented at IMEMTS 2007
 - Down-selected as the prime candidate as TNT replacement filling in 155mm M795 projectiles
 - BAE Systems OSI was contracted to manufacture IMX-101 in full production scale
 - Explosive Qualification
 - Projectile Loading Process Development









Passed Bullet Impact







Background (cont)

- IMX-101 successfully Loaded, Assembled & Packed (LAP) at US Army RDECOM ARDEC in the 155mm M795 projectile
- Qualification of IMX-101 explosive near completion
 - Aging trials result pending
- Qualification testing of IMX-101 explosive in M795 projectile also underway
 - Formal IM testing scheduled CY09
- IMX-101 filled M795 projectiles survived gunlaunched ambient, hot & cold at max charge (M198 howitzer, Yuma Proving Ground)
- IMX-101 also being considered for the next generation 105mm M1 cartridge and the 155mm M107 training ammunition











Program Objectives

- OSI and ARDEC to jointly establish a reproducible manufacturing process of IMX-101 at HSAAP under optimum operating conditions
 - Baseline parameters established (un-optimized)
 - Conduct experiments in production facility and compare results
 - Provide supporting information for material specification
 - Generate consistent material for loading trials at ARDEC
 - Desire to use Design of Experiment (DOE) approach to optimize processing parameters
 - Manufacture explosives using optimized processing parameters
- Finalize SOP, Material Specification and Manufacturing Instruction for the manufacture of IMX-101



ARDEC Picatinny Arsenal



Holston Army Ammunition Plant







IMX-101 Manufacturing Process Overview

Load Ingredients Melt and Mix Cast onto flaker belt

Molten IMX-101



Molten IMX-101 in thin strip



IMX-101 flakes

Pack and ship



Images shown are from the PAX-21 production







IMX-101 Manufacturing Process Overview (video)









Baseline Processing Parameters

- Baseline Processing Parameters identified from 1,200 lb production-scale batches of IMX-101 made in 2006
 - Processing temperatures at various stages
 - Ingredient Feed Rate & Order of Addition
 - Use of dry/wet ingredients
 - Final Incorporation (mixing) Time
 - Agitator Speed
- Material Processibility indicated by Efflux Viscosity and consistent Product Homogeneity
 - Composition, sensitivity and other physical/chemical properties testing
- Close interaction with ARDEC EM and LAP Producibility Teams
 - Immediate feedback on LAP

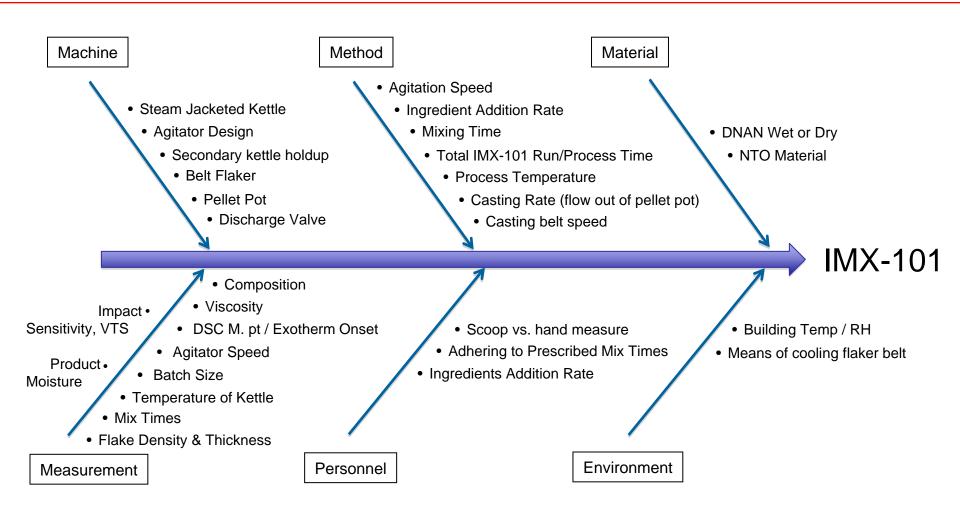








IMX-101 Producibility Parameters Considered









IMX-101 Producibility – Phase 1

- Leverage lessons learned from previous melt-pour and IM explosive development activities (e.g. PAX-21, PAX-41, PAX-196, etc)
 - All products utilized same production equipment
- Established nominal composition and tolerances based on user feedback on earlier production-scale batches
 - Attempted to optimize
 - ingredient addition rate
 - final incorporation time
 - agitator speed
 - intermediate holding vessel retention time











IMX-101 Producibility - Phase 1

- Desire by the customer (PM-CAS) to manufacture using set operating conditions to establish process parameters for LAP of the M795 projectile
 - Utilize nominal formulation and consistent IMX-101 production parameters to manufacture multiple batches
 - 24 batches delivered to the customer for LAP process development operations







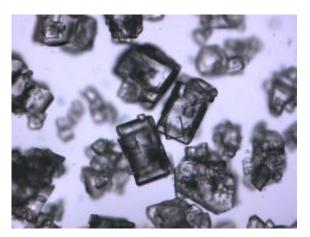




IMX-101 Producibility - Phase 1 Result

- Discovered variation of ingredients (particle size / shape) going into IMX-101 explosive led to independent evaluation
 - Extensive laboratory support for analysis and process optimization (e.g. NTO)
 - Obtained better understanding of product





13

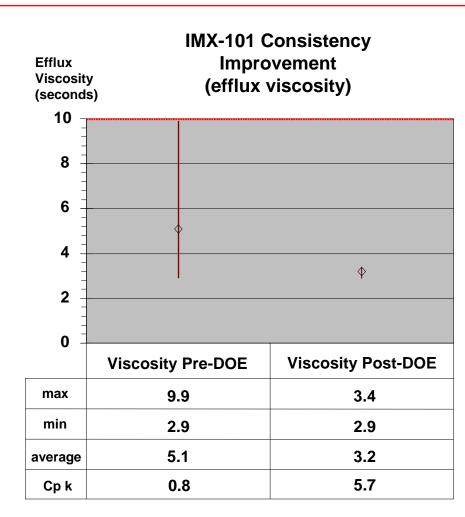






IMX-101 Producibility - Phase 1 Result

- Product appeared to be consistent, as measured by efflux viscosity, and other draft specification requirements
 - Occasionally, end user experienced difficulties in LAP operation even with what was believed to be consistent material
 - LAP producibility DOE was also conducted
 - There are likely other parameters that affect the quality of the M795 cast (porosity, cracking, etc)
 - It is recommended to conduct Phase 2 of the IMX-101 Producibility Study









IMX-101 Producibility - Phase 2 Follow-on Work

- Utilize Six Sigma Tools as a follow on to the LAP DOE and Conduct Explosive Producibility DOE to improve overall product
 - Work concurrently with ARDEC LAP Producibility Team to provide consistent explosive for LAP operation with no defects
- Investigate formulation ingredients (high/low)
 - Evaluate existing tolerance
- Optimize Processing Parameters
 - Final incorporation time
 - Ingredient addition rate
 - Agitator Speed / Design









Conclusion

- Over 20,000 lbs of IMX-101 have been manufactured
 - Still relatively "young" explosive, compared to Comp B, RDX, HMX & TNT
- Successful LAP and Gun Launch
- Explosive Qualification Nearing Completion
- Producibility of Explosive Demonstrated
- Qualification Testing in the M795 Underway
- Efforts underway for Large Scale Production Volumes in CY10



2009 Insensitive Munitions & Energetic Materials Tucson, AZ, May 11-14 2009



Press Technology of IHE Charges

A cost effective economical manufacturing method for IM

Richard Wild, Diehl-BGT-Defence



IMC – Maasberg is member of the IMEMG



An association of

European industrial companies

working on the field of Insensitive Munitions.





- STANAG 4170 qualified PBX compositions
- PBX filled Insensitive Munitions
- Test ranges for IM optimization

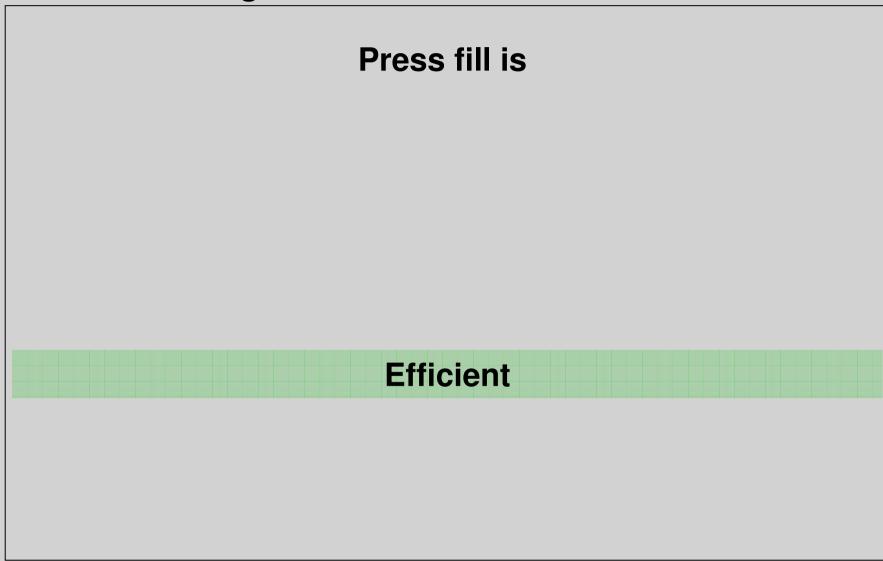














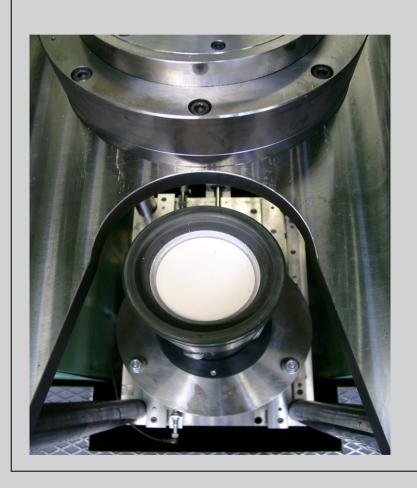
Press Fill, Molding Powder



- Water Slurry
 - safe coating process
- Granules
 - homogeneous coating
 - adjustable size
 - no segregation
- Bulk Material
 - no dust
 - free flowing
 - high bulk density



Press Fill, Compacting



- Pressure
 - less than 1kbar
 - for 5-10 seconds
 - at ambient temperature
- Direct into the shellCompacting from one side
- Final shape

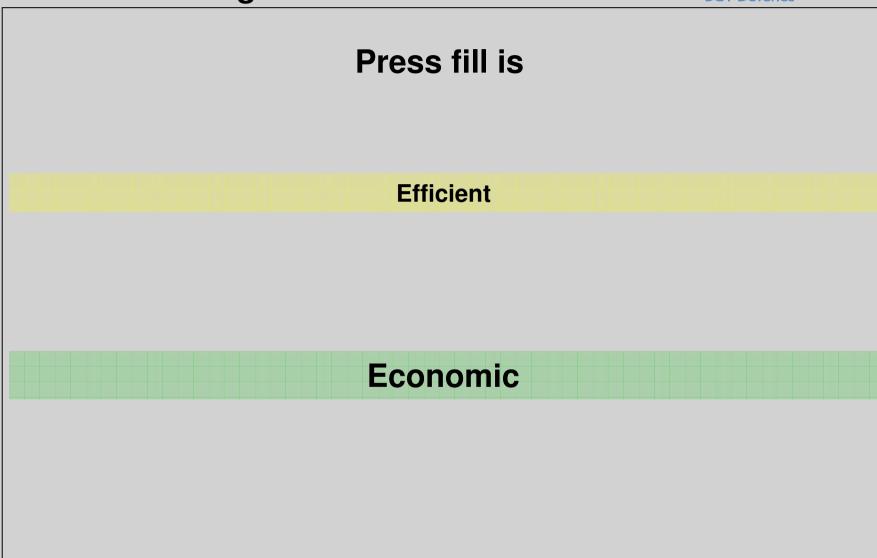


Press fill is

Efficient

- molding powder from a safe and separate water slurry process
- free flowing granules suitable for high speed dosing
- compacting direct into the shell
- final shape compacting
- minor need of cleaning







	i contor maacborg	BGT Detence
PBX Processing		
	Press Fill	Cast Cure
•	Dosing of the Granules (Ambient Temperature)	Homogenizing of the Components in a Kneader (Elevated Temperature)
		Addition of the Curing Agent (Elevated Temperature)
0	Compacting (Ambient Temperature)	Cast in Preheated Shells (Elevated Temperature)
		Polymerisation several days (Elevated Temperature)
0	Ready for Assembly	Ready for Assembly



Press Fill, Focal Points

- Higher efficiency for increasing production quantities
 - proportionate costs for the pressing tool
 - no waiting periods (e.g. for curing)
 - no accumulation of IHE-charges
 - quality check immediately possible
- Warhead Diameter smaller than 200 mm
 - moderate press size
 - length:diameter ratio about 3:1 for a one step compaction in a shell
- Warhead mass smaller than 15kg
 - moderate safety distances
 - possible damage (automatic process remote controlled)



Press fill is

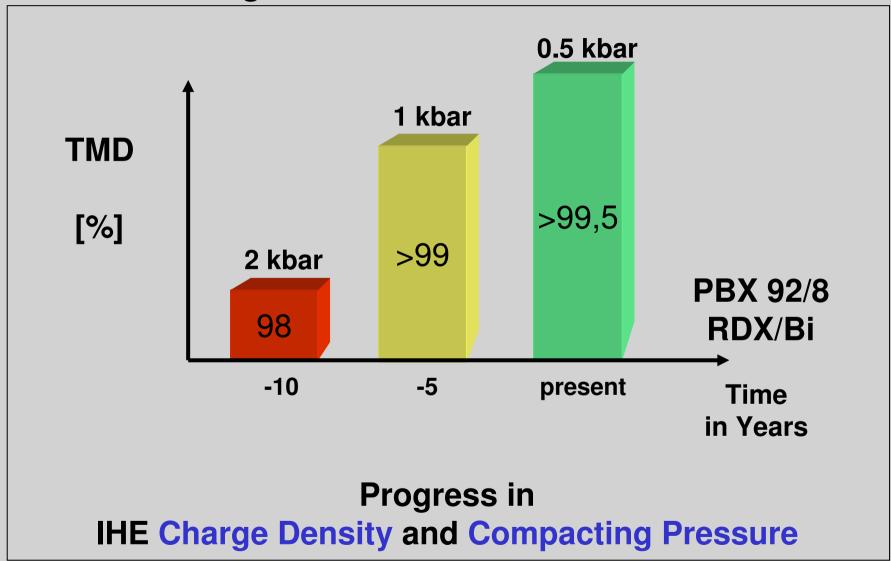
Economic

- 3 steps to the final HE charge in the shell
- ambient temperature process with little waste
- for high quantities
- for moderate WH diameters
- for moderate safety distances



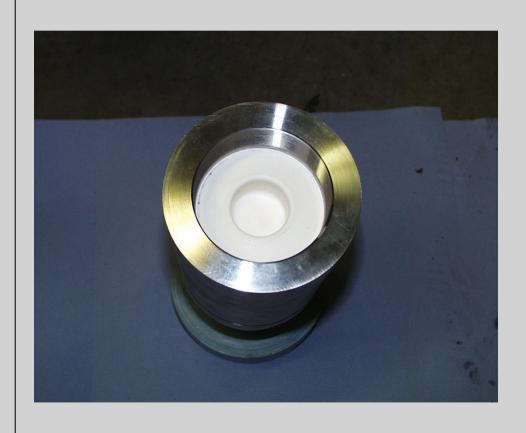








Press Fill, Charge Properties



- Quality
 - no gaps
 - no voids
- Density
 - close to TMD
- Gap Test, no go
 - more than 28 kbar
- Energy content
 - More than 90% solids



Press fill is

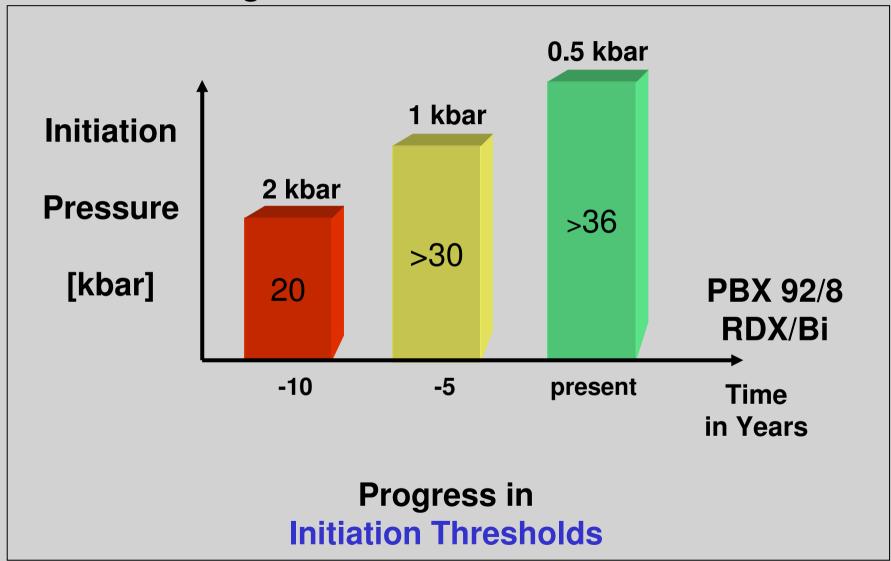
Effective

- density nearly 100% TMD
- no voids
- solid HE content > 90%











IM TECHNOLOGY







Test Setup



Test Result

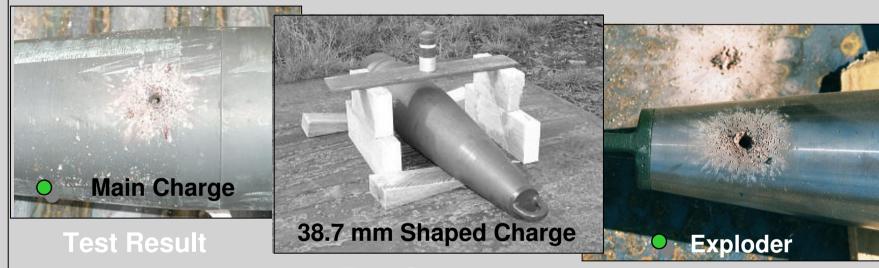
Press Filled PBX Round 40mm IM



No detonation transfer



IM TECHNOLOGY



Test Setup

Test Result

Press Filled PBX Round 155mm IM



SCJI Impact



Better than Type III Reaction



Press fill is

Safe

- low compacting pressure (< 1kbar)</p>
- high initiation level
- IM compatible
 - SD with 40mm pressed into the thin shell
 - SCJI with 155mm pressed into the confined shell



Press fill is **Efficient Economic Effective** Safe An economical and effective manufacturing method for **Insensitive Munitions**



Prepared by

Paul Anderson, Wendy Balas, Steven Nicolich, Chris Capellos, Jack Pincay: US ARMY ARDEC Leonard Stiehl: Polytechnic University

Prepared for:

NDIA Insensitive Munitions Energetic Materials Technology Symp.

May 12, 2009

Tuscan, AZ



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Development, Optimization, and Application of Combined Effects Explosives

12 May 2009



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- > Mr. Steven Nicolich
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- ➤ Mr. Gerard Gillen



> Mr. Paul Braithwaite



> Dr. Dave Downs













Outline



- Objectives
- CHEETAH Calculations
- Cylinder Expansion Results
- Optimization of Formulation
- Other Testing
- Conclusions
- Future Plans







Objectives



Develop and Demonstrate an aluminized explosive where the aluminum fully reacts in the early time of detonation and substantially contributes to the metal pushing energy of the explosive formulation and enhances blast.

- High Energy Explosive (LX-14)
 - Meet metal pushing performance
 - High nitramine content
 - High early work output (before 7V/V0)
- High Blast Explosive (PAX-3)
 - Meet blast performance
 - Typically aluminum and additional oxidizer
 - Later work output (after 7V/V0)
- Combined Effects Explosive
 - Meet LX-14 (metal pushing) AND PAX-3 (blast) performance with one explosive
 - Nitramine with fine aluminum: micron size
 - Aluminum reaction occurs very early and contributes to early work



Aluminum Particle Size

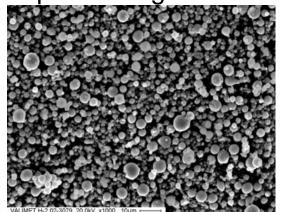


Nano-Aluminum

- Advantages
 - May react quickly and completely in a detonation for a complete release of energy
 - Claimed higher heat of formation than normal aluminum
- Possible disadvantages
 - Oxide coating may decrease performance.
 - Reactivity with air or water
 - Aging and stability in formulations not yet established.
 - Potentially higher cost
 - Requires modified processing methods

Micron Size Aluminum

- Advantages
 - Eliminates most of the disadvantages of the nano aluminum
- Possible disadvantages
 - Larger particle size may prevent fast enough reaction
 - Requires modified processing methods



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Formulations



					-	-	WANTED THE PROPERTY OF THE PRO
	LX-14	PAX-29	PAX-29n	PAX-30	PAX-3	PAX-3a	PAX-42
НМХ	95.5			77	64	64	
RDX							77
CL-20		77	77				
Al		15	15 (nano)	15	20 (39μm)	20 (3.5μm)	15
BDNPA/F		4.8	4.8	4.8	9.5	9.5	4.8
САВ		3.2	3.2	3.2	6.5	6.5	3.2
Estane	4.5						



PAX-29 (CL-20) CHEETAH 3.0 Calculations



COMPOSITION: Aluminized CL-20 3.2% CAB, 4.8% BDNPA/F 92% (CL-20 + Aluminum)	Density 99%TMD (g/cc)	CJ Pressure GPa	Detonation Velocity (km/s)	Expansion Energy @V/V0=6.5 E _{6.5} (kJ/cc)	Total Mechanical Energy E _{tot} (kJ/cc)
0% Al (PAX-22)	1.938	40.7	9.36	9.82	11.34
10% Al	1.984	39.6	8.98	10.55	13.26
13% Al	1.998	38.6	8.84	10.69	13.81
15% Al (PAX-29)	2.008	37.7	8.72	10.75	14.18
17% Al	2.018	36.5	8.60	10.76	14.55
20% Al	2.033	34.5	8.37	10.65	15.20
25% Al	2.058	32.2	8.04	10.28	15.92
30% Al	2.083	28.7	7.92	9.28	15.31

- E_{6.5} optimizes at 15-17% Al
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 25% Al

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



PAX-30 (HMX) CHEETAH 3.0 Calculations



COMPOSITION: Aluminized HMX 3.2% CAB, 4.8% BDNPA/F 92% (HMX + Aluminum)	Density 99%TMD (g/cc)	CJ Pressure GPa	Detonation Velocity (km/s)	Expansion Energy @V/V0=6.5 E _{6.5} (kJ/cc)	Total Mechanical Energy E _{tot} (kJ/cc)
0% Al	1.821	33.8	8.77	8.54	10.15
10% Al	1.874	32.6	8.43	9.37	12.03
15% Al (PAX-30)	1.902	31.3	8.16	9.70	12.98
18% Al	1.919	30.9	8.04	9.83	13.56
19% Al	1.925	30.7	8.02	9.84	13.77
20% Al	1.931	30.4	8.01	9.83	13.99
25% Al	1.960	28.4	7.99	9.62	14.95
28% Al	1.978	27.0	7.96	9.33	15.20
30% Al	1.991	26.2	7.94	9.00	15.09

- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al



PAX-42 (RDX) CHEETAH 3.0 Calculations



COMPOSITION: Aluminized RDX 3.2% CAB, 4.8% BDNPA/F 92% (RDX + Aluminum)	Density 99%TMD (g/cc)	CJ Pressure GPa	Detonation Velocity (km/s)	Expansion Energy @V/V0=6.5 E _{6.5} (kJ/cc)	Total Mechanical Energy E _{tot} (kJ/cc)
0% Al	1.745	30.7	8.51	8.06	9.66
10% Al	1.802	29.7	8.19	8.91	11.55
15% Al (PAX-42)	1.832	28.7	7.94	9.24	12.50
18% Al	1.851	28.6	7.84	9.37	13.07
19% Al	1.857	28.4	7.82	9.38	13.29
20% Al	1.863	28.1	7.80	9.37	13.50
25% Al	1.896	26.3	7.75	9.19	14.46
28% Al	1.915	25.0	7.70	8.89	14.67
30% Al	1.923	24.1	7.67	8.56	14.56

- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al



PAX-3 (HMX) CHEETAH 3.0 Calculations



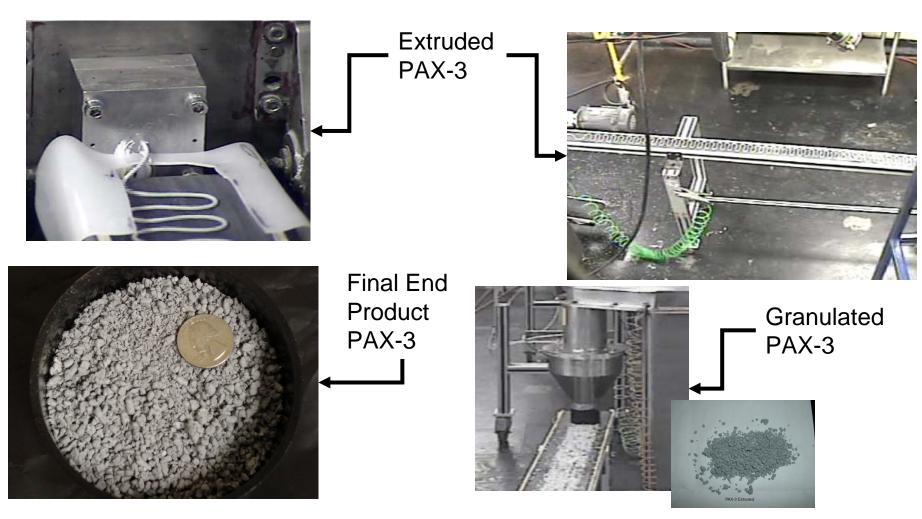
COMPOSITION: PAX-3 Variations 6.4% CAB, 9.6% BDNPA/F 84% (HMX + Aluminum)	Density 99%TMD (g/cc)	CJ Pressure GPa	Detonation Velocity (km/s)	Expansion Energy @V/V0=6.5 E _{6.5} (kJ/cc)	Total Mechanical Energy E _{tot} (kJ/cc)
0% Al	1.760	29.7	8.34	7.74	9.39
10% Al	1.810	28.3	7.99	8.52	11.13
15% Al	1.835	27.4	7.73	8.83	12.01
18% Al	1.851	27.1	7.65	8.94	12.58
19% Al	1.857	26.9	7.64	8.95	12.78
20% Al (PAX-3)	1.862	26.6	7.63	8.94	12.98
25% Al	1.890	24.8	7.58	8.73	13.86
28% Al	1.906	23.5	7.51	8.47	14.10
30% Al	1.918	22.6	7.47	8.17	14.01

- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al



Extrusion of PAX-3 MANTECH Funding





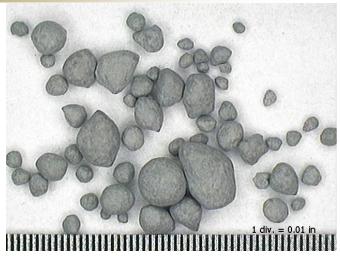
PAX-30 and PAX-42 are about to start development in twin screw extruder

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Molding Powder & Pressed Pellets

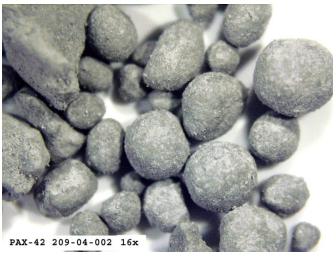




PAX-30 Powder made with vertical mix process



PAX-30 Cylinder Expansion Pellets



PAX-42 Powder made with vertical mix process



PAX-42 Cylinder Expansion Pellets

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LSGT Results



	LX-14	PAX-29	PAX-29n	PAX-3a	PAX-3	PAX-42
LSGT (cards)	193	135	130	128	124	110
Pressed Density (g/cc) (% TMD)	na	2.009 99.0%	2.005 98.3%	1.878 99.8%	na	1.842 99.5%

PAX-30 LSGT					
Vertical Mix Slurry Mixed Vertical Mixe					
162/165	160/161	161/162			
98.2% TMD	98.5% TMD	97.9%TMD			



RDECOM Metal Pushing & Blast Energy Compared to LX-14



Percent Change compared to LX-14				
HE	Metal Pushing/Unit Volume (Experimental)	Blast (Calculated)		
LX-14 (HMX) 0 (Baseline)		0 (Baseline)		
PAX-29c (CL-20)	17 %	43 %		
PAX-29n (CL-20)	17 %	38 %		
PAX-3 (HMX)	-28 %	32 %		
PAX-30 (HMX)	6 %	30 %		
PAX-42 (RDX)	3 %	24 %		

- PAX-30 and PAX-42 maintain metal pushing energy but exceed blast with 18.5% less explosive fill
- CL-20 increases sensitivity and cost not ready for development
- Excellent candidates for multi-purpose warhead!

GY DRIVEN. WARFIGHTER FOCUSED.



Cylinder Expansion Test Data (Gurney Energy)



	Comparison of Predicted and Actual Cylinder Expansion Results (V/V0=7)					
Formulation	Wall Velocity <i>v</i> (mm/µs) actual/predicted	Gurney Constant $\sqrt{2E}$ (mm/ μ s)	Predicted Gurney Constant (mm/μs)	Modified Gurney Constant (mm/µs) actual/predicted		
PAX-29n	1.965/1.944	3.078	3.046 (-1.0%)	3.135/3.102		
PAX-29	1.976/1.968	3.102	3.089 (-0.4%)	3.159/3.146		
PAX-29 (repeat)	1.976/	3.098		3.156		
PAX-30	1.855/1.890	2.968	3.023 (+1.9%)	3.022/3.078		
PAX-42 (EXP6 eos)	1.873/1.844 /1.790	3.045	3.002 (-1.4%) 2.914 (-4.3%)	3.101/3.057 /2.967		
LX-14	1.848/	3.014				

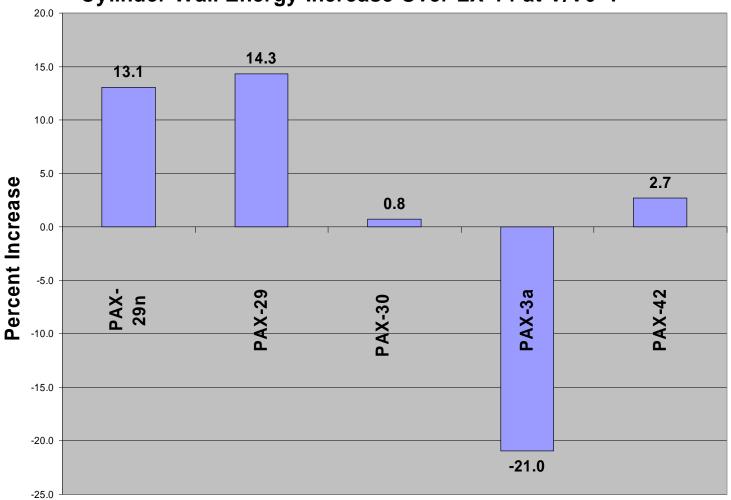
PAX-42 (an RDX version) meets LX-14 performance and has significant blast at a lower cost



Metal Pushing Compared to LX-14



Cylinder Wall Energy Increase Over LX-14 at V/V0=7



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PAX-30 DOE (Metal Pushing)

THE DEVICE OF THE PARTY OF THE

- Aluminum reaction is excellent for Al particles sizes from 130 nm to 15 micron
- 15 micron aluminum gives best performance at early and late expansion (blast vs metal pushing)
- There is a clear drop in performance with 30 micron aluminum



Comparison of Predicted and Measured Cylinder Expansion Tests for PAX-30 PAX-30 DOE – Effect of Aluminum Particle Size (92% Solids, 15% AL)					
Aluminum Particle	Density (g/cc)	Cylinder Wall Velocity (mm/µs)			
Size		V/V0=2	V/V0=7		
130nm	1.870 (96.8% TMD)	1.520 predicted	1.838 predicted		
		1.410 (92.7%) measured	1.830 (99.5%) measured		
3.5µ	1.909 (99.3% TMD)	1.560 predicted	1.888 predicted		
·		1.429 (91.6%) measured	1.855 (98.3%) measured		
8μ	1.885 (98.1% TMD)	1.550 predicted	1.881 predicted		
·		1.480 (95.5%) measured	1.856 (98.7%) measured		
15µ	1.889 (98.3% TMD)	1.554 predicted	1.883 predicted		
•		1.509 (97.1%) measured	1.887 (100.2%) measured		
30μ	1.878 (97.7% TMD)	1.546 predicted	1.874 predicted		
·		1.398 (90.4%) measured	1.791 (95.6%) measured		



PAX-30 DOE (Metal Pushing) Solids Level



- All 15 micron
- Moderate increase in theoretical performance with solids level
- Significant increase in measured performance with solids level
- 100% aluminum reaction efficiency at 92% solids

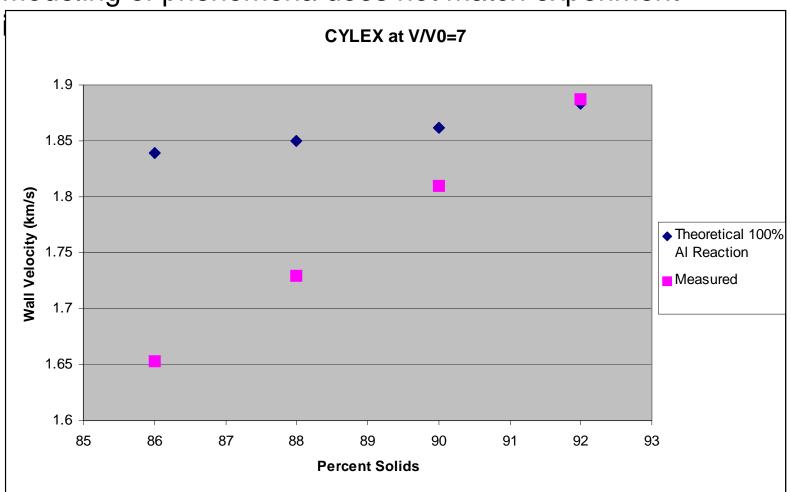
Comparison of Predicted and Measured Cylinder Expansion Tests for PAX-30 PAX-30 Optimization – Effect of Solids Level (15% 15µ AL)					
Percent Solids	Density (g/cc)	Cylinder Wall Velocity (mm/µs)			
		V/V0=2	V/V0=7		
86	1.863 (99.6% TMD)	1.504 predicted	1.839 predicted		
		1.339 (89.0%) measured	1.653 (89.9%) measured		
88	1.868 (98.9% TMD)	1.516 predicted	1.850 predicted		
		1.397 (92.1%) measured	1.729 (93.5%) measured		
90	1.871 (98.2% TMD)	1.526 predicted	1.862 predicted		
		1.458 (95.5%) measured	1.810 (97.2%) measured		
92	1.889 (98.3% TMD)	1.554 predicted	1.883 predicted		
		1.509 (97.1%) measured	1.887 (100.2%) measured		



PAX-30 Cylinder Expansion Optiization



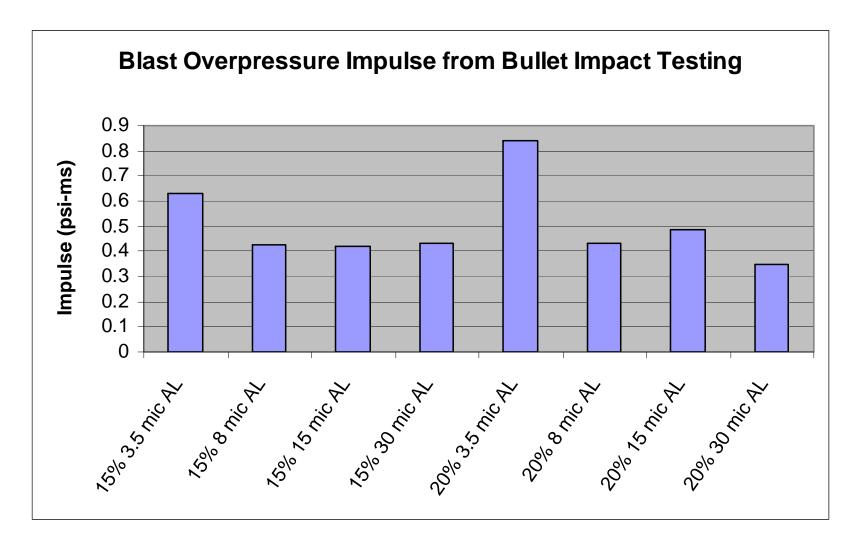
- Data shows consistent trends
- Modeling of phenomena does not match experiment





PAX-30 DOE – Bullet Impact (1/21b bare billet)







Summary - PAX-30 Formulation Studies



- PAX-30 DOE study shows that 15 micron aluminum at the 15% level offers the following benefits
 - Best performance
 - Better pressed density than smaller Al sizes
 - Better bullet impact response than 3.5 micron Al
 - Reduced cost compared to smaller Al
 - Reduced aluminum ESD sensitivity compared to smaller Al
- The PAX-30 optimization study shows that performance is greatly reduced at solids levels below 92%
 - Bullet impact improvement seen only at the lowest (86%) solids level

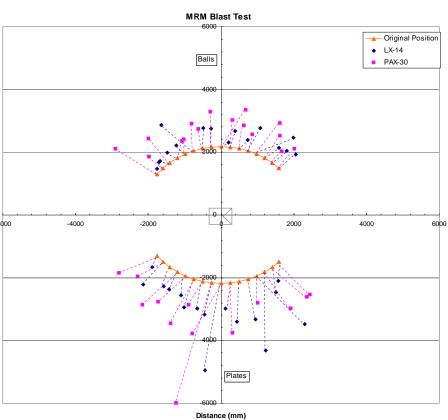
PAX-30 optimizes metal pushing and blast at 92% solids and 15micron Aluminum



MRM Stonehenge - PAX-30 and LX-14







- •Blast capabilities outperformed LX-14 in the MRM configuration.
- PAX-30 maintained penetration equivalent to LX-14

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PAX-30 3.2" IM Testing MIL STD 2105C



Test	# of Tests		Reaction	
Explosive		LX-14	PAX-30	PAX-42
Bullet Impact	2	Type IV	Type III	Type IV
Fragment Impact	2	Type IV	Type III	Type III
FCO	2	Type IV, Type V	Type IV	Type 1, Type III
SCO	2	Type III, Type V	N/A	Type III, Type V

* Initial Assessment



FI



Unreacted Material PAX-30

BI

TECHNOLOGY DRIVEN. WA

FCO

Unreacted Material

"Distribution A: Unlimited Distribution"



Summary



- High energy/high blast (combined effects) explosive formulations have been demonstrated; PAX-29 and PAX-30 and PAX-42 formulations have been tested and verified to exceed the metal pushing energy of the baseline explosive LX-14 while substantially exceeding the blast energy
- Several formulations were developed in which proper size aluminum was demonstrated to react completely in the very early time of detonation, which contributes to the metal pushing energy
- In this formulation it is not necessary to use nano aluminum to achieve early time reaction
- PAX-30 possesses over 30% more Gurney Energy with equivalent blast capability to other standard aluminized explosives such as AI Comp A3
- Eigen detonation theory used to explain behavior
- EOS equations have been developed





DEVELOPMENT OF INSENSITIVE ALUMINIZED MELT-POUR EXPLOSIVE FORMULATION

NDIA Insensitive Munitions & Energetic Materials Technology Symposium 2009



Virgil Fung *, Brian Alexander BAE SYSTEMS OSI, Holston Army Ammunition Plant

Wendy Balas RDECOM-ARDEC, Picatinny Arsenal





Briefing Objectives

- Background
- Program Objectives
- Technical Approach
- Formulation Candidates
- Test Results
- Additional Information
- Summary







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 - Ms. Wendy Balas

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 - Mr. Curtis Teague
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 - Mr. Matt Hathaway
 - Mr. Alberto Carrillo
 - Ms. Kelly Guntrum





Background

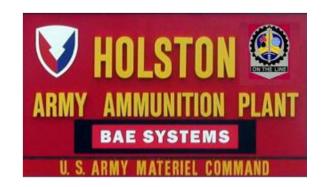
- PAX-28 Formulation Replacement Program
 - Develop new explosive formulation with similar performance and handling characteristic and IM properties to PAX-28
 - PAX-28 Formulation
 - 2,4-Dinitroanisole (DNAN)
 - Aluminum powder
 - RDX
 - Ammonium Perchlorate (AP)
 - PAX-28 is developed as an IM replacement for TNT/Comp B, and is targeted for high blast applications
 - New formulation candidates must be <u>without</u> Ammonium Perchlorate (AP)
 - Health Issues (exposure to handlers)
 - Manufacturing Friendliness (moisture control)
 - Environmental Issues (waste treatment)





Program Objectives

- Developed new formulation candidates to meet customer's requirement
- Conduct lab scale experiment to generate sample for analysis
 - Processibility
 - Hazard Properties
 - Physical / Chemical Properties
- Conduct intermediate scale manufacturing for large scale testing
 - Shock sensitivity HSAAP
 - Performance (plate dent) HSAAP
 - Large Scale Blast Performance (GD-OTS)
- Successful candidate may lead to further optimization and ultimately full production scale manufacturing for further evaluation



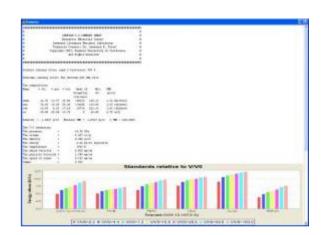






Technical Approach (1)

- 1. Performance Prediction Modeling
 - Cheetah performance prediction model used initially to assess candidates with various ingredient combinations:
 - Theoretical Maximum Density (TMD)
 - Detonation Velocity and Pressure
 - Energy Release (kJ/cc explosive)
 - The performance model prediction is only used as a guide to assist selection
 - Aluminized formulations did not behave the same way as conventional explosive in Cheetah prediction







Technical Approach (2)

- 2. Small Scale Manufacturing
 - Candidates are manufactured through a series of mixing trial with various ingredient combinations
 - Processibility will be assessed
 - Efflux Viscosity
 - Sedimentation
 - Physical appearance
 - Thermal and hazard testing
 - DSC / VTS / Impact & Friction Sensitivity









Technical Approach (3)

- 3. Small Scale Performance Testing
 - To evaluate the blast performance of the candidate, the
 Plate Dent Test is carried out
 - PAX-28 used as the baseline
 - 1" thick x 5" square low carbon steel witness plate
 - Candidates loaded in LSGT tube (no card gap used)
 - One Pentolite Booster pellet per shot
 - Damage on plate (dent) measured and compared to baseline
 - Duplicate charges fired for each candidate
- 4. Large Scale Gap Test (NOL)
 - To evaluate the shock sensitivity of leading candidates and compare with PAX-28
 - 50% Card Gap for PAX-28 ~ 131 cards (MSIAC Newgates v1.6)







Technical Approach (4)

- 5. Large Scale Blast Testing
 - To evaluate the large scale blast performance of the candidate
 - Test vehicle & method described in the technical paper "Comparison of Blast Performance of the IM Explosive PAX-28 Variations", presented at IMEMTS 2007
 - PAX-28 used as the baseline
 - Duplicate charges fired for leading candidate
 - Intermediate scale manufacturing (50 LBS) to supply material for the large scale blast test
 - Further formulation optimization based on the result of the large scale blast test







Photos courtesy of GD-OTS





Candidate Formulations

- 2 candidate formulations were developed for assessment
 - OSX-11
 - DNAN + NTO + Aluminum powder
 - OSX-12
 - DNAN + NTO + RDX + Aluminum powder
- Nitrotriazolone (NTO) used in general to replace AP
- Aluminum powder remains as per PAX-28 to create the blast effect
- Proof of concept no formulation optimization in this phase





Candidate Formulations

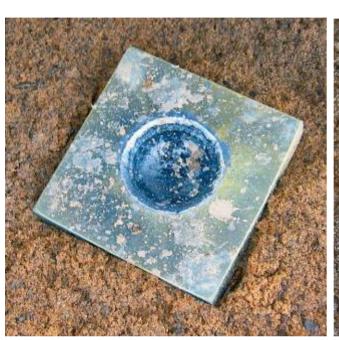
	OSX-11	OSX-12
Ingredients	DNAN, NTO (two grades) and Aluminum Powder	DNAN, NTO, RDX and Aluminum Powder
Efflux Viscosity at 96°C	~ 10 seconds	~ 5 seconds
Impact Insensitive – Naval Impact	0/10 fire at 220cm	2/6 fire at 220cm, no fire at 200cm
VTS (100°C/48 hours)	N/A	0.06 ml/g
DSC Onset	233°C	255°C
Predicted P _{cj} = % of PAX-28 (Cheetah 5)	95.7%	93.0%
Predicted VOD = % of PAX-28 (Cheetah 5)	96.7%	99.4%
Predicted Energy Release = % of PAX-28 (Cheetah 5)	96.9%	86.0%





Plate Dent Test Result

- 1. OSX-11
 - Both charges initiated successfully
 - Dent did not penetrate witness plates fully



OSX-11 Charge 1 NEQ = 262.44g Dent Depth ~ 0.68"



OSX-11 Charge 2 NEQ = 262.93g Dent Depth ~ 0.63"



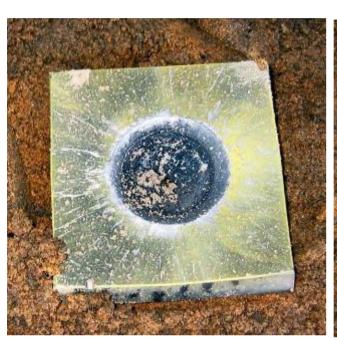






Plate Dent Test Result

- 2. OSX-12
 - Both charges initiated successfully
 - Dent did not penetrate witness plates fully



OSX-12 Charge 1 NEQ = 264.60g Dent Depth ~ 0.83"



OSX-12 Charge 2 NEQ = 264.37g Dent Depth ~ 0.87"

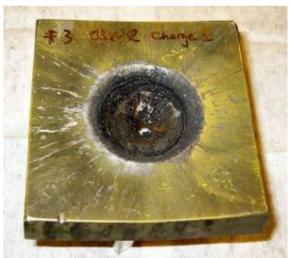








Plate Dent Test Result

- 3. PAX-28 as baseline
 - Both charges initiated successfully
 - Dent did not penetrate witness plates fully
 - Dent Depth very similar to OSX-12



PAX-28 Charge 1 NEQ = 254.76g Dent Depth ~ 0.89"

PAX-28 Charge 2 NEQ = 255.17g Dent Depth ~ 0.86"









Plate Dent Test Summary

- The dent depth of OSX-12 (0.83" & 0.87") and PAX-28 (0.89" & 0.86") were almost identical, suggesting their metal accelerating abilities can be considered as comparable
- Based on the dent depth, OSX-12 (0.83" & 0.87") appears to be more powerful than OSX-11 (0.68" & 0.63), although the performance model predicted otherwise (P_{cj} and energy release)
- At this point, all effort was focused on OSX-12 in the next phase of evaluation







Large Scale Gap Test & Large Scale Blast Test

- NOL LSGT conducted on OSX-12
- Charge Density ~ 1.81-1.82 g/cc
- 50% card gap of OSX-12 = 131 cards (46.6 kbar)
- Shock sensitivity identical to PAX-28
- 30 lbs of OSX-12 manufactured and delivered to GD-OTS for large scale blast test
 - Compare blast performance with PAX-28
 - Test date yet to be determined
 - Test result will determine whether the OSX-12 formulation requires to be optimized
 - More solids can be added due to low viscosity







Additional Information (1)

- OSX-12 possesses good processibility
 - Low efflux viscosity (more solids can be added if necessary)
 - Significantly lower than PAX-28
 - Little sign of sedimentation even distribution of solids in liquid







Additional Information (2)

- OSX-12 has been evaluated in a 60mm mortar fragmentation test
 - Cast iron mortar body
 - PBXN-5 booster
 - Mortar fully detonated
 - Fragment pattern acceptable
 - Base witness plate
 - Side witness plates (1' and 2' away)
 - Fragment size desirable









Additional Information (3)

- OSX-12 has undergone hazard testing in accordance to TB 700 for the application of EX Number
 - Thermal Stability (mass loss at 75°C over 48 hours)
 - 0.03% mass loss
 - Did not exhibit ignition or explosion or thermal runaway
 - Impact Sensitivity (BOE Impact)
 - Not sensitive to impact at drop height of 10.5cm, drop weight of 8lb (12 tests)
 - Small Scale Burn Test
 - Showed no detonation but burned intensely for 2 minutes 54 seconds
 - Friction Sensitivity
 - not sensitive to friction when tested up to 14,065 psi of pressure
 - Above test results shall lead to successful EX number application





Summary

- OSI has taken the approach of replacing Ammonium Perchlorate (AP) in PAX-28 with Nitrotriazolone (NTO)
- NTO is readily available at HSAAP and is a key ingredient in many new insensitive melt-pour formulations such as IMX-101 and IMX-104
- Comparative dent depth between OSX-12 and PAX-28 suggests OSX-12 has matched PAX-28 in terms of metal accelerating ability
- IM properties of OSX-12 assumed to be similar to PAX-28, based on identical LSGT result
- DOT EX Number test results and VTS results suggest OSX-12 possesses excellent IM properties
- Preliminary fragmentation test suggests OSX-12 can produce adequate fragmentation performance in certain configuration
- Good processibility (low viscosity) suggests OSX-12 can easily be scaled up to full scale production
- Large scale blast test result against PAX-28 will indicate whether OSX-12 (in its current form) is an adequate replacement





Advances in Cast Cure Explosives

2009 NDIA IM & EM Technology Symposium Tucson, AZ

May 11-14, 2009

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IM testing of 3.2" generic shaped charges:

Bullet and fragment impact performed by General Dynamics Ordnance and Tactical Systems under contract to ARDEC

Fast and slow cookoff performed by National Technical Systems' National Ordnance, Munitions, and Environmental Test Center under subcontract to General Dynamics





Outline



Objective and approach

Performance

Processing

Subscale Insensitive Munitions (IM) testing

- Shock sensitivity in LSGT
- Slow cookoff in VCCT

IM testing in 3.2" generic shaped charge warheads

Bullet impact, fragment impact, slow cookoff, fast cookoff
 Summary





Objectives and Approach



Objectives: Develop new cast cure explosives that meet the following criteria:

- Improved performance over PBXN-110 (for HMX formulations)
- Equivalent or better IM response than PBXN-110

Approach: Use a proven binder system which has given good IM and processing properties

- •Formulate DLE-C051 to exceed PBXN-110 for metal-driving applications
- Formulate DLE-C050 to exceed PBXN-110 performance for dual purpose applications – metal driving and blast
- Formulate DLE-C053 to provide best cost and performance balance





Theoretical Performance



Cheetah performance prediction comparison to PBXN-110:

- DLE-C051 has 4.5% increase in Energy @V/V₀=6.5
- DLE-C050 has 31% increase in total mechanical energy (blast)
- DLE-C053 slightly lower energy than PBXN-110 but still very good

Formulation	DLE-C050	DLE-C051	DLE-C053	PBXN-110
P _{ci} (Kbar)	247	264	231	249
V _d (km/s)*	7.59	7.89	7.58	7.75
CJ Temperature (°K)	4734	3757	3768	3682
Energy @ $V/V_o = 6.5 \text{ (kJ/cc)}$	8.15	7.22	6.7	6.91
Total Mech Energy (kJ/cc)	11.46	9.10	8.6	8.77





Processing



One of the primary goals in the development of new castable explosives is to optimize processing

Factors to consider include:

- Ability of binder to wet solids
- Final mix viscosity
- Flowability of explosive through typical casting tooling

Excellent flow of mixes and good casting quality



Cast surface of DLE-C050



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Shock Sensitivity



Large Scale Gap Tests (LSGT) conducted

- Sensitivity similar to PBXN-110
- DLE-C053 used standard solid explosive
 - Opportunities to further improve shock sensitivity may be possible through the use of specially prepared material

Formulation	Go/No-go # Cards
DLE-C050	173/175
DLE-C051	176/177
DLE-C053	175/176





Slow Cookoff (VCCT) DLE-C050



Relatively mild VCCT reactions were observed

- Sample heated at 6 °F/hour.
- Steel sleeve in two large pieces at 0.090" wall thickness



VCCT Test at 0.090 in. Wall Thickness

Variable Confinement Cookoff Testing of DLE-C050					
Wall Thickness	Reaction Level				
(in.)	(°F)				
0.030	359	burn			
0.045	333	pressure rupture			
0.060	360	pressure rupture			
0.075	367	pressure rupture			
0.090	342	deflagration			





Slow Cookoff (VCCT) DLE-C051



Relatively mild VCCT reactions were observed

- Sample heated at 6 °F/hour
- Steel sleeve in three large pieces at 0.090" wall thickness



VCCT of DLE-C051						
Wall Thickness	Reaction Temperature	Reaction Level				
(in.)	(°F)					
0.030	360	pressure rupture				
0.045	357	pressure rupture				
0.060	358	pressure rupture				
0.075	355	deflagration				
0.090	371	deflagration				





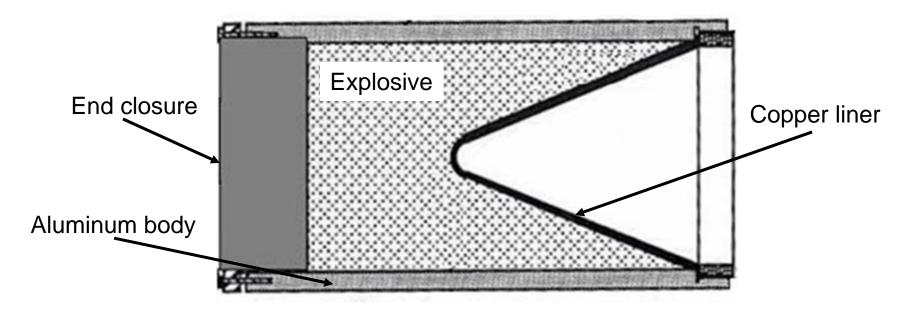
IM Testing in 3.2" Generic Shaped Charges



Device loaded with approximately 2 lb of explosive

Bullet impact, fragment impact, slow cookoff, and fast cookoff performed

Only DLE-C050 and DLE-C051 tested at this time









Bullet Impact Testing of 3.2" Generic Shaped Charges



Single 50 caliber armorpiercing bullet targeted 5.75" from liner end

Test Monitoring

- Over pressure gages
- High speed digital video
- Standard video
- Witness plates
- Velocity screens

Warhead Fill	Projectile Velocity	Gage Pressure Readings	Witness Plate Markings	Result
DLE-C050	2865 ft/s	none	none	Type V (burn)
DLE-C051	2846 ft/s	none	none	Type V (burn)





Bullet Impact Testing of 3.2"Generic Shaped Charges

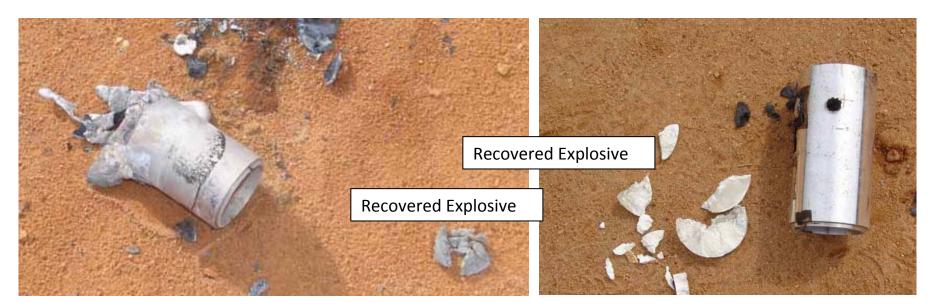


End closures dislodged from main body

Copper liners remained intact

Explosive fill ignited and burned

No debris thrown more than 50 ft



DLE-C050

DLE-C051





Fragment Impact Testing of 3.2" Generic Shaped Charges



Single conical mild steel projectile at ~6000 ft/s

Test Monitoring

- Over pressure gages
- High speed digital video
- Standard video
- Witness plates
- Velocity screens

Warhead Fill	Projectile Velocity	Gage Pressure Readings	Witness Plate Markings	Result
DLE-C050	6087 ft/s	none	none	Type V (burn)
DLE-C051	6110 ft/s	none	none	Type V (burn)





Fragment Impact Testing of 3.2" Generic Shaped Charges



Warhead cases split open by fragment impact
Debris scattered in the immediate vicinity of test stand
No debris thrown more than 50 ft



DLE-C050



DLE-C051

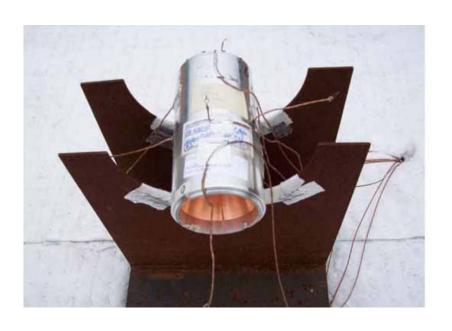




Slow Cookoff Testing of 3.2" Generic Shaped Charges



Slow cookoff performed at 6 °F/hour heating rate



Test Monitoring

- Over pressure gages
- Standard video inside and outside oven
- Witness plates
- Thermocouples of oven and skin temperature

Warhead Fill	Reaction Temperature	Gage Pressure Readings	Witness Plate Markings	Result
DLE-C050	350.0 °F	none	none	Type V (burn)
DLE-C051	353.4 °F	none	none	Type V (burn)





Slow Cookoff Testing of 3.2" Generic Shaped Charges





Warheads remained essentially intact and lay next to test stand



DLE-C050





DLE-C051

Internal video showed extruding explosive deformed copper liners Gases vented past deformed liners after ignition





Fast Cookoff Testing of 3.2" Generic Shaped Charges



Fast cookoff performed above fuel basin containing 500 gallons of kerosene



Test Monitoring

- Over pressure gages
- Standard video
- Thermocouples for air temperature near test article

Warhead Fill	Average Flame Temperature	Time to Ignition	Gage Pressure Readings	Result
DLE-C050	1611 °F	33 s	none	Type IV (deflagration)
DLE-C051	1768 °F	13 s	none	Type V (burn)





Fast Cookoff Testing of 3.2" Generic Shaped Charges



Small pieces of burning explosive thrown to 30 ft

Copper liner ejected past 50 ft

DLE-C050 main body found 9 ft from test stand in fuel basin



DLE-C050

DLE-C051 body and liner remained in wire basket and burned (melted) in the fire



DLE-C051





Summary



Two new cast cure explosives developed

- DLE-C050 and DLE-C051
- Compositions have predicted performance better than PBXN-110

Characterization started on a third promising formulation in this family of cast cure explosives (DLE-C053)

Low cost and high performance

Formulations have excellent processing characteristics

Shock sensitivity similar to PBXN-110

IM response of DLE-C050 and DLE-C051 excellent in 3.2" shaped charges

Warhead Fill	Bullet Impact	Fragment Impact	Slow Cookoff	Fast Cookoff
DLE-C050	Type V (burn)	Type V (burn)	Type V (burn)	Type IV
				(deflagration)
DLE-C051	Type V (burn)	Type V (burn)	Type V (burn)	Type V (burn)



GUNTOL – A Low Cost Melt Cast for IM

Anna_TMaria Amnéus and Per Sjöberg, Eurenco Bofors
Henric Öştmark, FOI

2009 Insensitive Munitions & Energetic Materials

Technology Symposium

May, 11-14, 2009

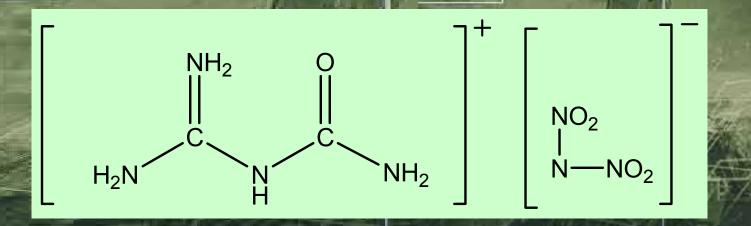
Loews Ventana Canyon Resort, Tucson Arizona, USA

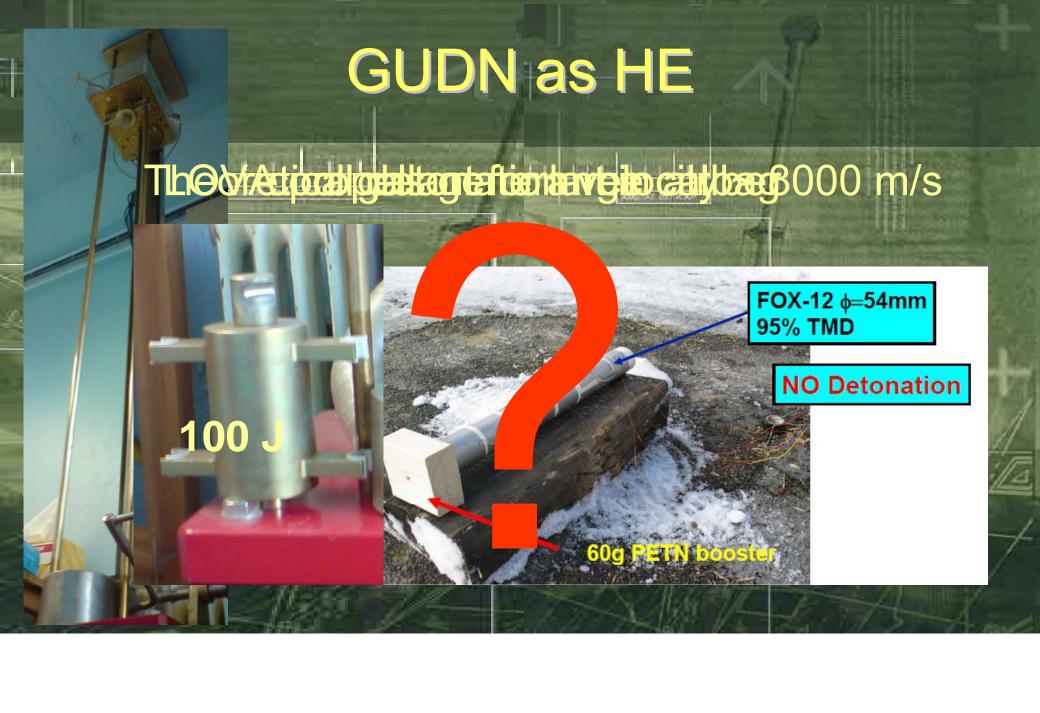


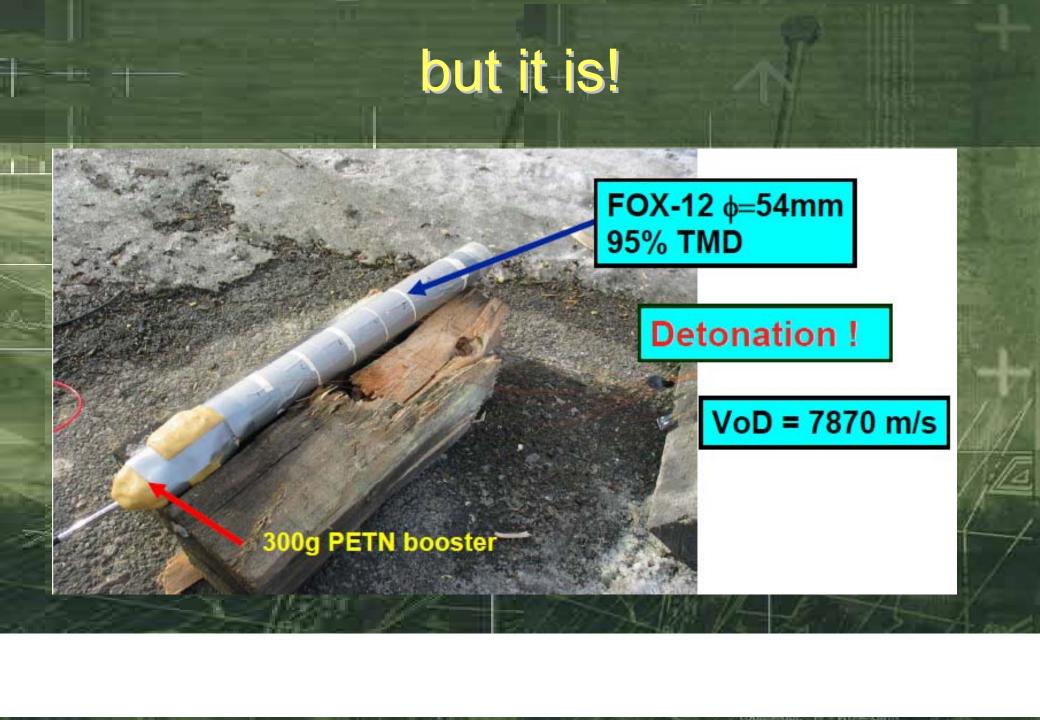
Name: Guahylurea dinitramid, FOX 12

Formula: [NH₂C(NH)NHCONH₃]+ [N(NO₂)₂]-

CA\$ nr: 217464-38-5



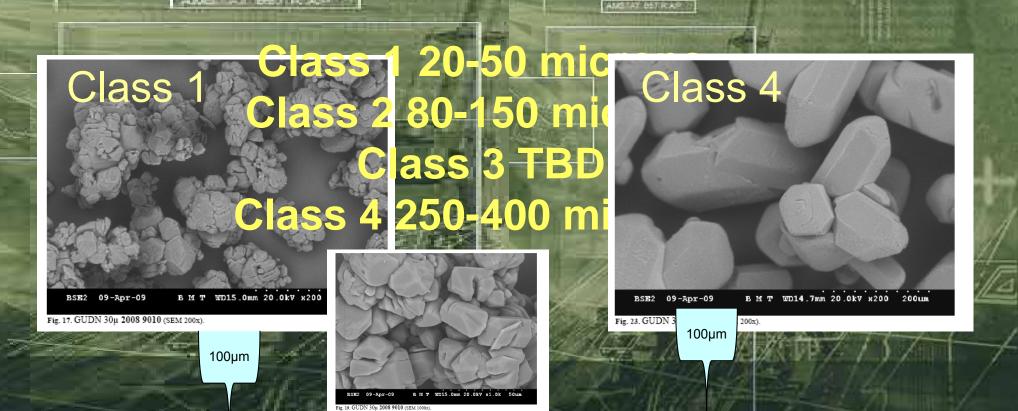


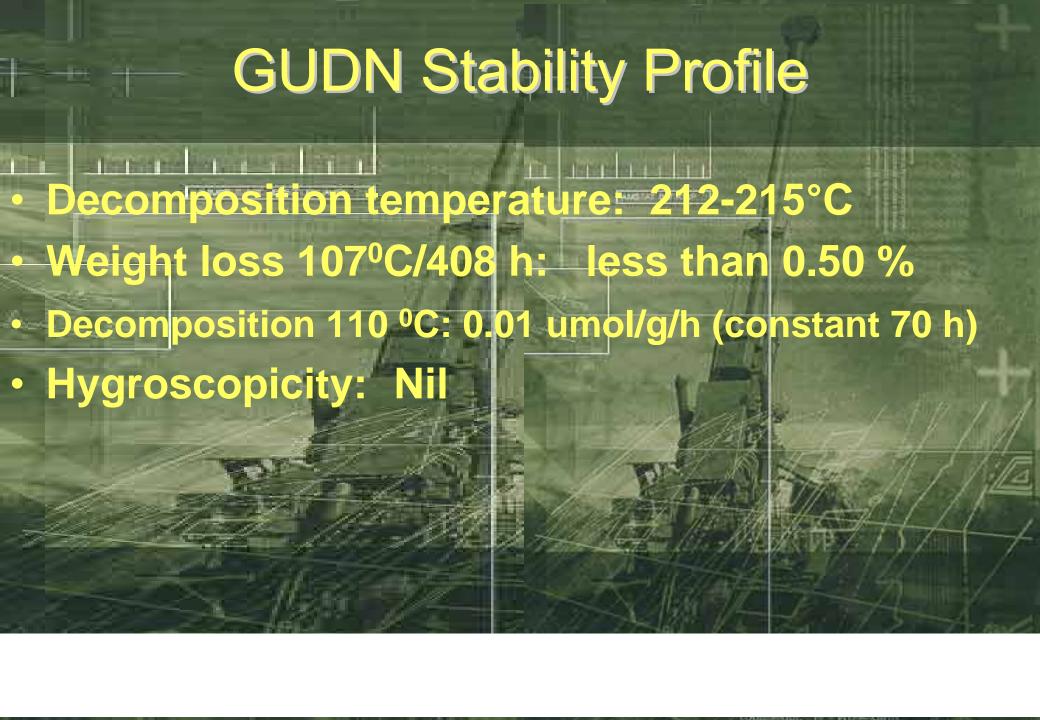


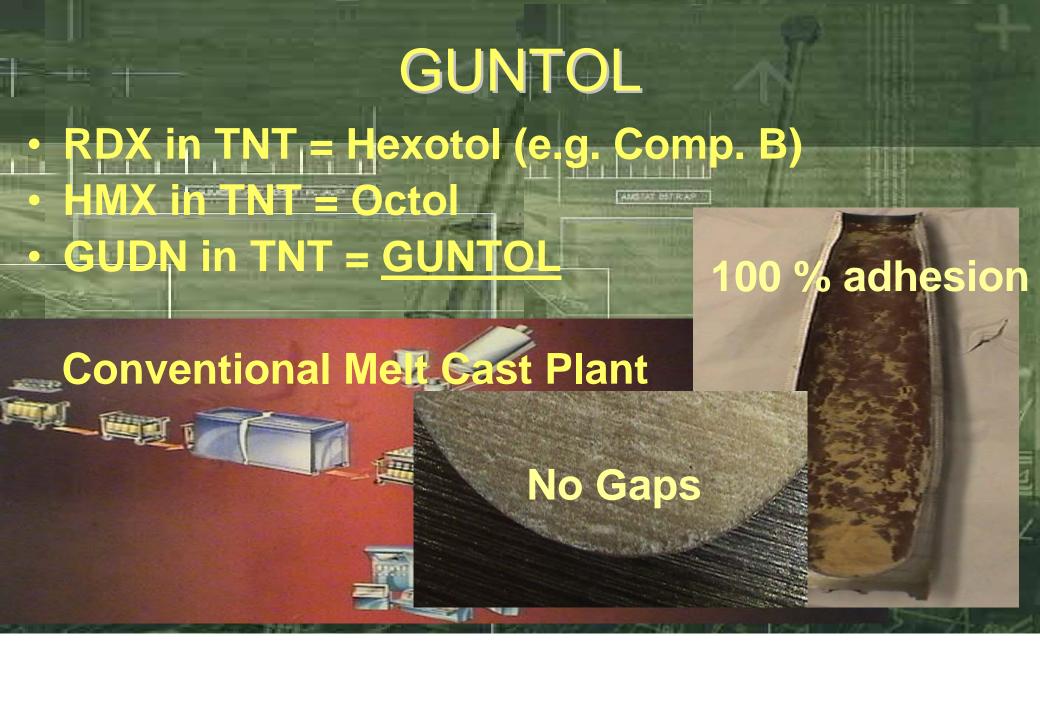


GUDN Particles

Four classes (particle sizes) are produced







USING TNT - is that a problem?

--- An amorf structure is obtained by adding HNS

Adsorbent (> 30 years experience)

cracks

and

porosities

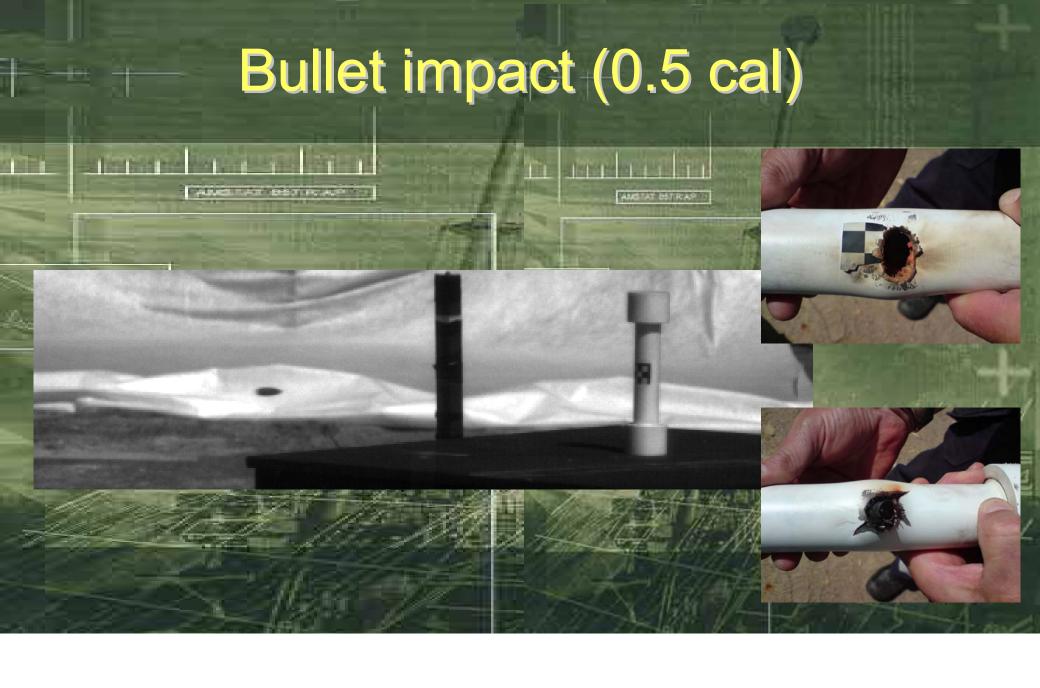
8 MPa

Exudation reduced 70% at 70 °C
 TNT compositions are still widely used

- If you still lack confidence in TNT
 - Use GUDN in dinitroanisol (DNAN)
- Don't forget the price tag: 1-2 USD/lb!

solid and amorf

13 MPa

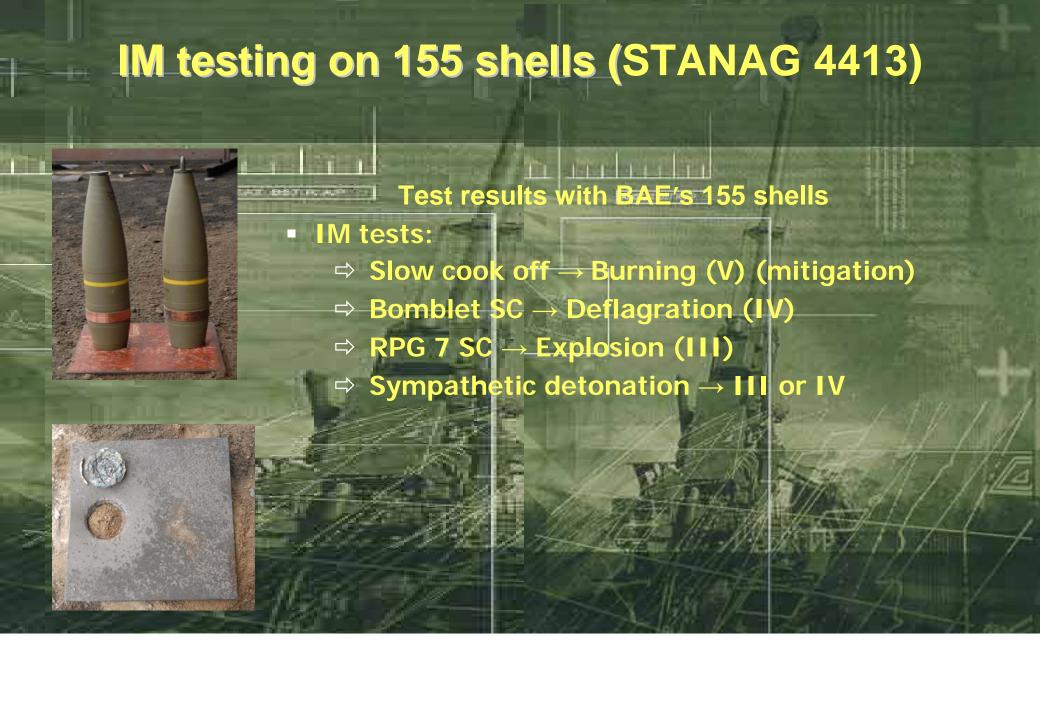


SSGT (shock sensitivity) testing

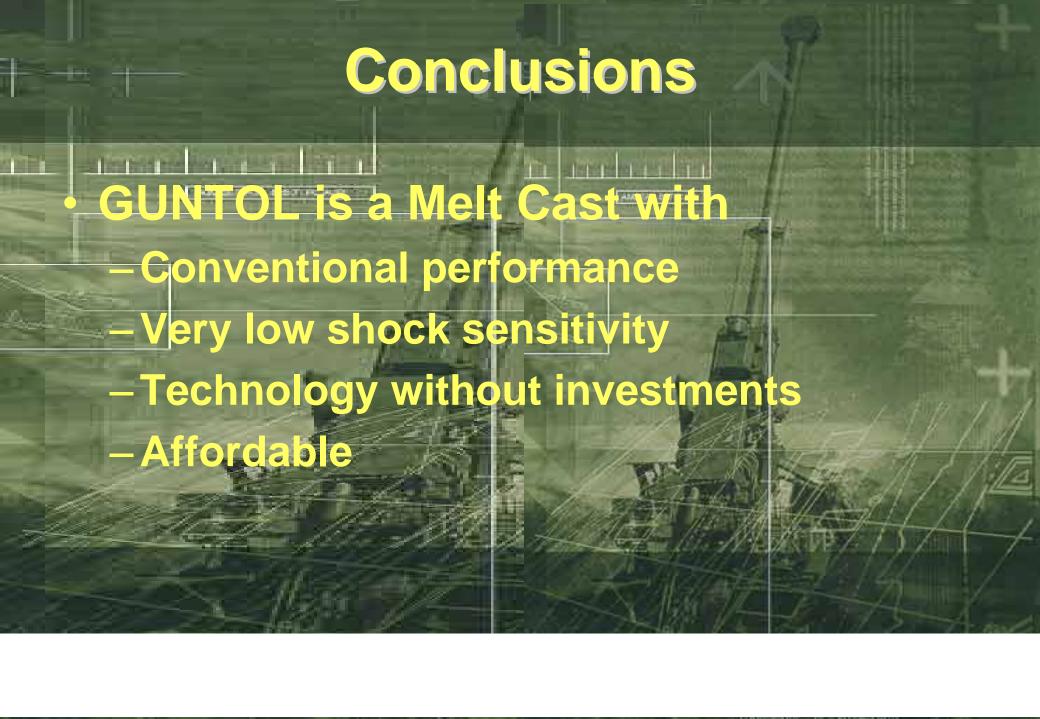
[] [] [] [] [] [] [] [] [] []	Inert —	HMX	TNT	GUDN	SSGT mm water
GUNTOL			55	45	0.9
GUNTOL + HMX +"plasticiser"	5	10	35	50	1.0
GUNTOL + RDX + AI		15	35 15	35	4.4
Composition B					18
PBXN-110					14/
TATB			V 10 1		1////

Gurney (performance) testing

Calca consequence of	RD	X⊥	HMX		AI	GUDN	Gurney km/sec
PBXN-109	65	The same			15		1.88
PBXN-110			90		7/7/		2.21
GUNTOL		# 2		55		45	2.07
GUNTOL + HMX			25	40		35	2.44
GUNTOL + RDX + AI	15			35	15	<mark>35</mark>	2.23
	7.			6, 4		7//	11/1/
	7					/67	13/1-
							4











Munitions Safety Information Analysis Center







HEAT AND DARTS



Test Results Database



Pierre Archambault





2009 Insensitive Munitions & Energetic Materials Technology Symposium

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HEAT & DARTS

Aim to

- Compare response of various
 - Munitions
 - Energetic materials
- Assess the impact of similar stimuli
- Provide data to validate models
- Increase confidence in response through statistic



HEAT & DARTS

Contents

- -Response of the tested item
- -Tested item characteristics
- Test setup characteristics
- Test procedures



Structure

Introductory Sheet

SCO Datasheet

SCO

Detailed Response

FCO Datasheet

FCO

Detailed Response



Introductory



- Datasheet
 - -System



-Threat



-Response



- Detailed response sheet
 - -Semi quantitative data



Quantitative data





Structure

Introductory

DATABASE

Setup Diagram

Shaped Charges

Bibliography

Test Vehicles

Test Procedure

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Introductory



- Database
 - -Tested munitions



-Shaped charge



Barrier/mitigation



Initiation mechanism & reaction type



Other information



Other sheets

- Set up Diagram
 - SC setup dimensions
- SC
 - Characteristics
 - Sketch
- Test vehicles
 - Generic test units
 - Characteristics
 - Sketch



HEAT & DARTS

Summary

- Two new databases
- Results of IM tests on munitions/components
 - FCO and SCO (HEAT)
 - Shaped Charge Jet aggression (DARTS)
- Available from MSIAC (end 2009)
 - At info@msiac.nato.int
 - On MSIAC secure web https://sw.msiac.nato.int/secureweb
- For MSIAC nations



HEAT & DARTS

Supplementary slides





Introductory sheet





HEAT

Fast & Slow Heating Results

Version 1.0

SCO DATA

FCO DATA

Contact data

Problems/Questions: MSIAC or Pierre Archambault

Phone: +32-2-707-5416 or +32-2-707-5447

Email: msiac@msiac.nato.int

or p.archambault@msiac.nato.int

2009

Neither MSIAC, nor the participating Nations can guarantee nor warrant the adequacy, accuracy, currency or completeness of the technical information contained in this database

Link to datasheet





Datasheet

- System
 - Test configuration
 - Tested items characteristics
 - Fields are searchable/sortable using filter

SYSTEM										
Munition Designation	Type of Item	Cfg.	Item Orient.	Energetic Materials			Thermal Liner	Simulant Dummy	Munitions Mitigation Device	
				ID.	Туре	Amount (kg)				





- Datasheet
 - Threat (FCO)
 - Stimuli and test set up characteristics
 - Fields are searchable/sortable using filter

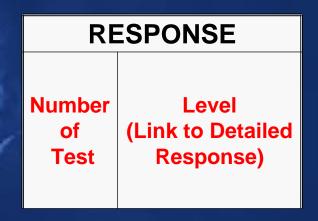
	THREAT										
1	Type of FCO	Fuel Type	Hearth Size (m)	Distance between Item and Fuel Surface (mm)	Type of support	Nb. Of TC	TC Location	Average Temp. (°C)	Wind Speed (km/s)	Test Procedure	





Datasheet

- Response
 - Response level
 - Fields are searchable/sortable using filter
 - Level link to data in detailed response sheet







- Detailed response sheet (FCO)
 - Semi quantitative data
 - Fields are searchable/sortable using filter
 - Level response linked to datasheet

	RESPONSE											
Nb. Of Tests	Level	Nb. of Events	Initial Reaction		Second Reaction		Third Reaction		Propulsion	Witness Plate Data		
			Time (m:s)	Туре	Time (m:s)	Туре	Time (m:s)	Туре				





- Detailed response sheet
 - Quantitative data
 - Fields are searchable/sortable using filter

RESPONSE									
Air Bla	st Data	Longest Distance Travel By a 150 g Fragment (m)	F	gments lying more than 15 m	Thermal F	Flux Data	Pressure Wave Velocity (km/s)		
Max. Press. (mbar)	Gauge Loc. (m)		Nb,	Energy at 15m (J)	Max. (kW/m2/s)	Gauge Loc. (m)			





Introductory sheet

DARTS

Database of Ammunition Reaction Trials to Shaped Charge Aggression

Version Beta





Problems/Questions: MSIAC or Pierre-François PERON

Phone: (+32) 2 707 54 16 or (+32) 2 707 54 26

Email: msiac@msiac.nato.int or p-f.peron@msiac.nato.int

2008

Test Setup Diagram

Please Click On The Following Links

- 1. Database 🔨
- Test Setup Diagram
- 3. Information on Shaped Charges <
- 4. Information on Generic Test Units
- 5. Bibliography
- 6. STANAG 4526 Test Procedure

Link

to

sheets

Chardes / Test Verlicles / Sheet1 / Biblight

Contact Data

Introduction DATABASE





Database

- Tested munitions
 - Munitions designation
 - Energetic materials name & composition
 - Aiming point & test configuration
 - Tested items characteristic
 - Fields are searchable/sortable using filter

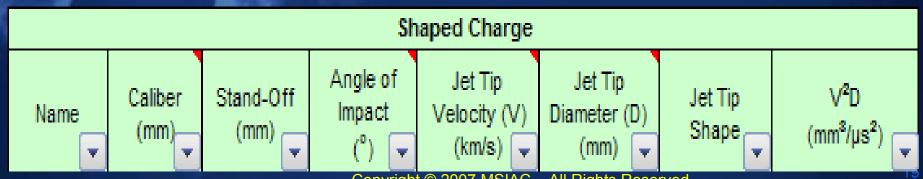
		Teste	d Munition				
Name •	Energetic Material	Composition	Aim point	External Diameter (mm)	Case Thickness (mm) 🔽	Case Material	Configu- ration





Database

- Shaped Charge
 - Designation & caliber
 - Stand off distance
 - Angle of Impact
 - Jet characteristics
 - Fields are searchable/sortable using filter

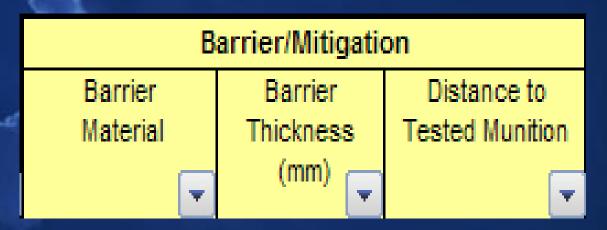






Database

- Barrier/Mitigation
 - Material
 - Thickness
 - Distance between barrier and tested munitions
 - Fields are searchable/sortable using filter







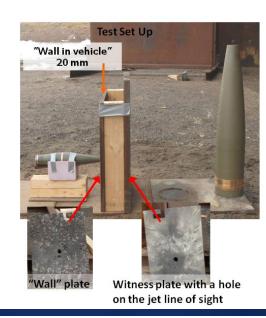
RPG-9 Shaped Charge (73 mm) Impact on 155mm HEER Shell Filled with TNT and 55%GUDN / 45%TNT Compositions

Database

- Initiation mechanism
- Reaction type
 - Linked to test details
- Other information
 - Reference number
 - Comments



section







Initiation Mechanism

Reaction Type

Other Information

References | General Comments





SOUTH AFRICAN NAVY 76/62mm AMMUNITION EVOLUTION FROM PRIORITISATION TO THA TO CHARACTERISATION AND EVENTUALLY IM COMPLIANCE

12 MAY 2009 TUCSON, ARIZONA

C.M. Brijraj, F.C. Fouché







AGENDA

- INTRODUCTION
- IM PRIORITISATION
- THREAT HAZARD ASSESSMENT:
 - New software approach
- IM CHARACTERISATION
- IM TECHNOLOGY FOR HIGH SET-BACK APPLICATIONS
- CONCLUSION
- ACKNOWLEDGEMENTS







INTRODUCTION

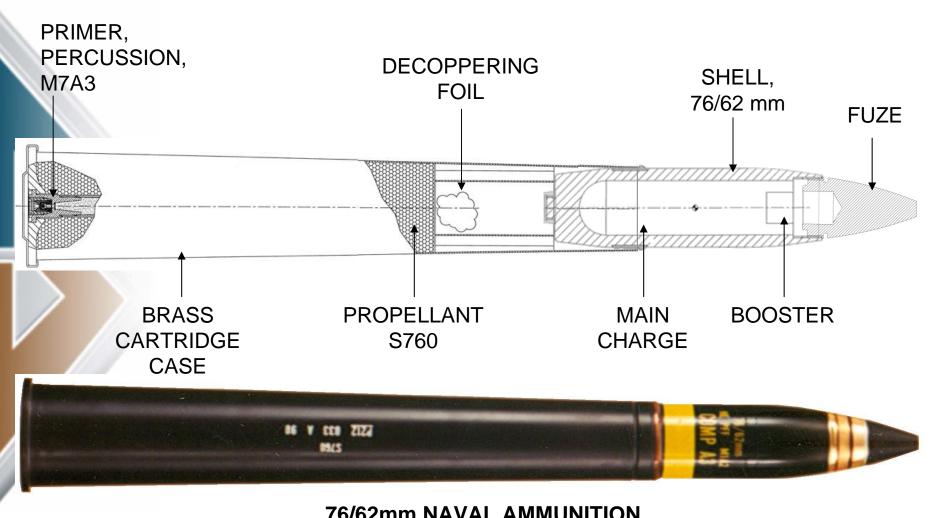
- The road to IM compliance
- IPT approach
- Various players
- The naval 76/62 mm ammunition is a "vehicle" to illustrate the "road" to IM compliance







INTRODUCTION



76/62mm NAVAL AMMUNITION







INTRODUCTION

• THE SA DODI LOG NO 00053/2005 (ED. 1) POLICY ON IM CALLS FOR INTER ALIA THE FOLLOWING:

Auditable Outcomes

- A comprehensive schedule reflecting the IM characterisation of all ammunition in order of priority.
- Complete insensitive munitions characterisation of existing stock.
- The achievement of IM compliance requires a systems approach. Where, even with the systems approach it is not possible to achieve full IM compliance, reduction in risk becomes the overall objective.





IM PRIORITISATION

- The prioritisation process was shown
- The 76/62mm Medium Gun Weapon (MGW) naval ammunition was starting point
- Extensive work already done on the 76/62mm ammunition
- IM prioritisation leads the way
- Not much benefit in performing IM characterisation tests hastily
- A paper titled: THA methodology, a South African approach



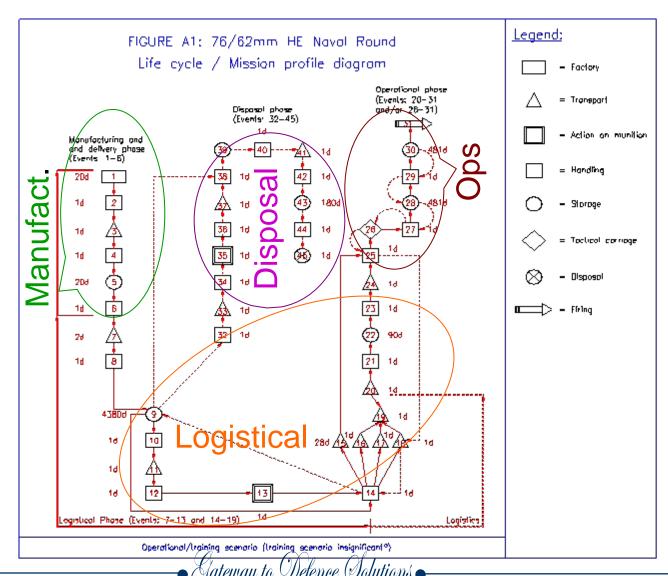




THREAT HAZARD ASSESSMENT

LIFE CYCLE

DIAGRAM







THREAT HAZARD ASSESSMENT

- Each situation was analysed
- Historically MS Excel was used
- The likelihood of situation, threats and responses determined
- Probability of a major event calculated
- Technically involved for the user community







New Software Approach

The SA IM steering committee new approach

- Use of a MS Access database program
- Engage the stakeholders
- User friendly
- Central registry
- Facilitate standardisation
- Ease of cross reference to the THAs
- Applicable to all arms of service
- Facilitator of IPT had "drop down" menu



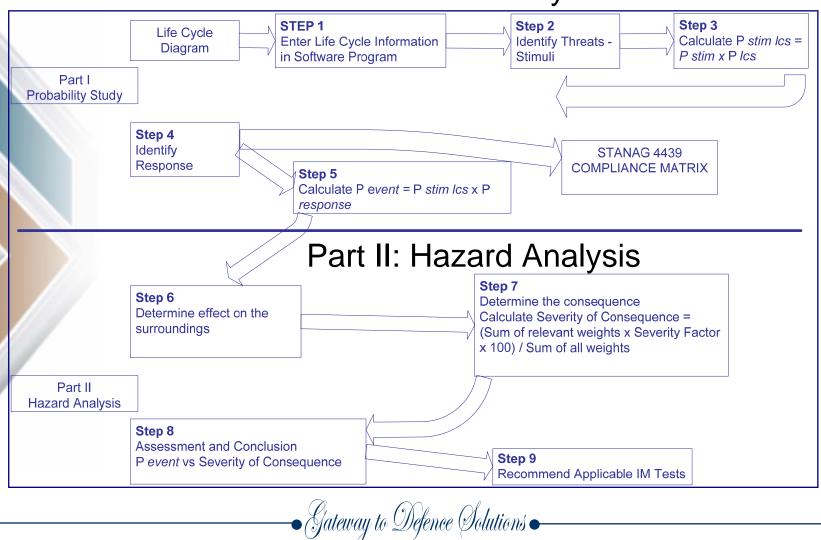


10



New Software Approach

Part I: Prob. Analysis







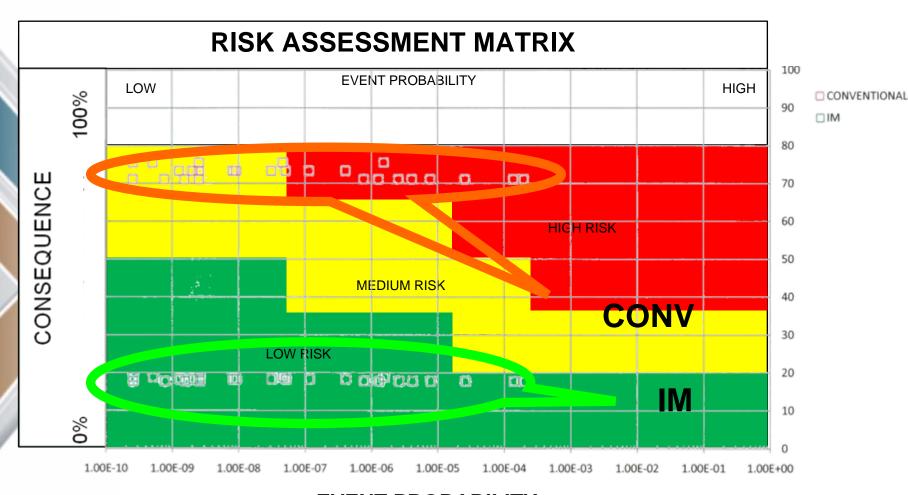
New Software Approach

Life Pha	ase ID Life Phase	e Description	ا	Life Phase Notes				Duration/Days	Repeats
HE 0201	THE SECOND SECON	g.: Handling - Depot Loa	ad/Uload,	8,10,12,14,16,18,23,24,26,28	Logisti	cs: Ha	andli	ing 0	1
	Manual / F			000	at Dep	ot		- 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
<u>.</u>	Ammunition Type	Stimulius	Probability	Threat - Stimulus Notes			Response	Probability Response Notes	
	76/62mm HE Plugged	Fragment Impact	1.00E-00	60mm; 81mm Mortar; 8-18 p	gd, 23-28 tzd	State of the Art Product	Type I	In	
•	76/62mm HE Fuzed	Fragment Impact	1.00E-06	60mm; 81mm Mortar; 8-18 p	gd, 23-28 fzá	State of the Art	Type I	process	
						Product	Type I	of	
	76/62mm HE Plugged	Spall Impact	0.00E+00	-; 8-18 plgd, 23-28 fzd		State of the Art	Type I	updating	
						Product	Type I		
	76/62mm HE Fuzed	Spall Impact	0.00E+00	-; 8-18 plgd, 23-28 fzd		State of the Art	Type I		
						Product	Type I		
•	76/62mm HE Plugged	Shaped Charge Jet Impact	0.00E+00	RPG 7; 8-18 plgd, 23-26 fzd		State of the Art	Type I		6
			5			Product	Type I		
	76/62mm HE Fuzed	Shaped Charge Jet	0.00E+00	RPG 7; 8-18 plgd, 23-28 fzd		State of the Art	Type I	1.00E+00 Type I-II Always, Ty	pe III 50%
		Impact				Product	2	CONV	
	76/62mm HE Plugged	Sympathetic Detonation	1.00E-03	Palletised; 8-18 plgd, 23-28 f	zd	State of the Art	Type		50%
						Product	Type	Or time OCE+00 Type I-V Always	
	70/00mm	O	4.005.00	Dellational, 0.40 minut, 00.00 f			Tu		
	76/62mm HE Fuzed	Sympathetic Detonation	1.00E-03	Palletised; 8-18 plgd, 23-28 fa	ZQ	State of the Art	ıy	IM	





New Software Approach



EVENT PROBABILITY





IM characterisation results for various 76/62 mm naval ammunition types

	Type	FCO	SCO	SD	SD (mono- cont)	BI	FI	SCJI
7001	HE	///	/	///	NR	V (main) II (expl)	II (main) II (expl)	l (main) l (expl)
	HE PFF	<i> </i>	/	//	NR	V (main)	l (main) l (expl)	III (main) I (expl)
4	AA Flash	///	///	///	NR	///	///	NR (main) I (expl)
	Su Prac	///	///		NR	IV	IV	///





Figure 5: Liquid Fuel Fire for 76/62 mm ammunition test set-up



Test was conducted in accordance with STANAG 4240







Figure 6: Liquid Fuel Fire for 76/62 mm HE ammunition test results





The remains shows that the reaction was an explosion which is the third most violent event. This was as expected.

Figure 7: Liquid Fuel Fire for 76/62 mm SU PRAC ammunition test results



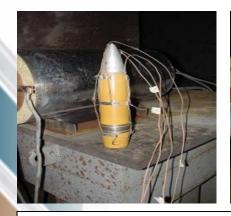


This result shows that an explosion for the SU Prac was also obtained primarily because of ignition of propelling charge.





Figure 8: Slow Cookoff for 76/62 mm ammunition test set-up







STANAG 4382 was used with a heating rate of 5°C/ hour and the test item was preheated to 60°C in the interest of time saving.

Figure 9: 76/62 mm AA Flash Slow Cookoff results



This result shows that an explosion for the AA Flash was obtained with limited remains of the oven.







Figure 10: Bullet Impact Test Set Up



Test was conducted according to STANAG 4241. Target range determined as 30m. Impact was through main charge and also exploder charge.



Figure 11: Bullet Impact test results for 76/62 mm HE and PFF through main charge

No reaction observed through main charge, but a type II observed through the more sensitive exploder charge (CH6)









Figure 12: 76/62mm SU PRAC Sympathetic Detonation (SD) test set up

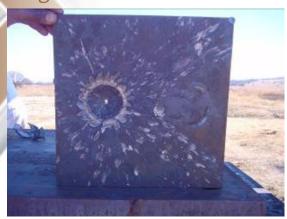




STANAG 4396 (1991) donor acceptor/basis test. Gap determined to be 20mm. Donor was detonated by electric detonator.

Witness plate positioned at acceptor

Figure 13: 76/62 mm HE SD results







A type III reaction was obtained. There was a significant indentation on the 20mm witness plate. There is some unexploded energetic material in the debris.





Figure 14: 76/62 mm HE SD results (packaged in mono-containers)





A type V (no reaction) was obtained and this is because the transfer of the detonation from the donor the acceptor was mitigated by the aluminium wall of the mono-container that deformed and absorbed some of the energy. This prevented the violent reaction. It is evident that just by changing the packaging that IM can be achieved on a system level.







Figure 15: Shaped Charge Jet Impact test set up

Shaped charges (diameter 32mm) were utilized with a 100 mm air gap between shaped charge and the test item. Witness plates were placed around the test.



Figure 16: 76/62mm HE PFF Shaped Charge Jet results



A type III reaction was obtained when aimed at the main charge and type I at the exploder charge.







Figure 17: Test set up for Fragment Impact (FI)



A conical shaped projectile made of mild steel is fitted into a plastic sabot then into a 30mm round. The weapon is positioned approx 10m away. Charge adjustment performed until impact velocity of 1830+/- 60 m/s was reached. Fragment aimed at the target by direct aiming through the barrel, onto a mark on the target object.



Figure 18: Test results of 76/62mm AA Flash





Type III reactions were obtained when aiming at the flash pellet. (TNT/AI). Note there is no main charge.





- IM applicable technology project is referred to as PBX and IM for high set-back munitions
- Initiated several years ago
- International papers presented
- The funding facilitates know-how and IM technology insertion
- Managed by ARMSCOR through a joint defence industry initiative by the Rheinmetall Denel Munition group







- Ammunition incorporates a booster, main and exploder charge.
- Initial years RXHR-5 was main charge and HSKF-2 as the booster charge
- Exploder charge was NREV 9502 (NTO/RDX/EVA) or HXHR 9201 (HMX/Hytemp/Plasticizer) or RXHR 9501 (RDX/Hytemp/Plasticizer)
- Now promising pressed PBX formulations include
 NTO based NREV 9506 and RDX based RXHR-5







Figure 19: Liquid Fuel Fire test result for 76/62 mm filled shell with main charge NREV 9506 with no booster





Shell was recovered without any damage. Burning type V reaction was observed. It must be noted that the conventional filling RDX/Wax (91/9) showed a type I reaction after 2 minutes and 40s.

Figure 20: Shaped Charge Jet Impact set up and results: RXHR-5 main charge formulation





Jet entered and exited the shell at the main charge using RXHR-5. A burning reaction type V was observed for a 50mm plate and type 1 for a 25mm, both with 40mm air gap.





Figure 21: Bullet Impact test set-up/results NREV 9506 and HNS/KeIF booster





12,7mm AP showed a burning reaction type V

Figure 22: Test set up for Sympathetic Detonation with varying air gap for RXHR-5







The picture 22b shows that when there is a 20mm air gap there is somewhere between a type III and type IV reaction. The picture 22c on the right shows the result for an 80 mm air gap which shows minor damage to the shell and is thus classified as a type V reaction.





IM performance characteristics (lethality)

Static performance tests were carried out and the fragment velocity as well as fragment penetration tests on mild steel plates of 2,5mm; 4,5mm; and 6mm thickness







RXHR-5

NREV 9506

RDX/WAX







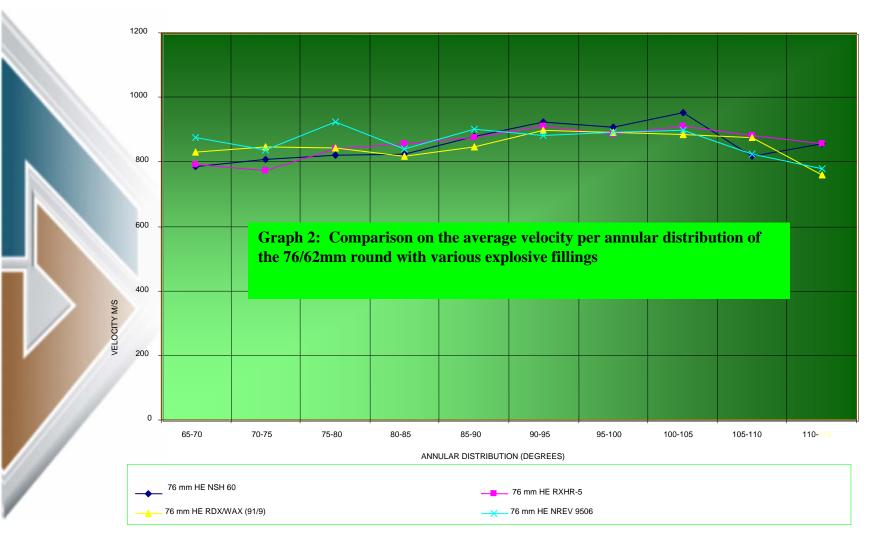








Table 3: Summary of IM characterisation tests performed

rable 3. Summary of the characterisation tests performed						
Explosive Formulations	FCO	SD	BI (12,7mm AP)	SCJI (40mm air gap)		
76/62 mm HE: Main Charge NREV 9506 (NTO/RDX/EVA) Booster: None	V	V (80mm gap)V (40mm gap)IV (20mm gap)	V	V (50mm armour plate) I (25mm armour plate)		
76/62 mm HE: Main Charge NREV 9506 (NTO/RDX/EVA) Booster: HNS/KeIF	V	No evaluation	V	No evaluation		
76/62 mm HE: Main Charge: RXHR-5 Booster: None	V	V(80mm gap) 40mm gap) - pressure burst Between III and IV (20mm gap)	V	V (50mm armour plate) I (25mm armour plate)		
76/62 mm HE: Main Charge: RDX/WAX (91/9)	1	V(80mm gap) IV (40mm gap) I (20mm gap)	111	l (50 mm armour plate)		





CONCLUSION

- The systematic and methodical approach was used for the 76/62 mm SA Navy ammunition
- Process requires commitment from all the stakeholders and an IPT approach
- Significant progress made in reducing vulnerability
- Packaging also plays an important role
- Hoped for process to be followed diligently in SA
- Comparison, maturity build up and technology insertion







ACKNOWLEDGEMENTS

The speaker will hereby like to acknowledge Mr Wolmarans, Capt (SAN) Steyn, Mr Fouché, Mr Pentz, Mr du Toit, Mr Niemand, Mr Vels and Mr H Bezuidenhout who did the ground work and provided support.

LOVE ALL SERVE ALL





































Safety

MSIAC Wh

What's TEMPER?



Overview

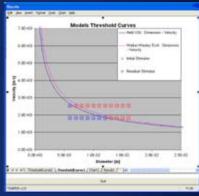
- TEMPER, an acronym for Toolbox for Engineering Models to Predict Explosive Reactions, is a "library" of models dedicated to ammunition safety.
- TEMPER, developed by DGA/CEG, has been made available through NATO/MSIAC to experts from MSIAC member nations.
- Since the first version in 2004, many improvements have been brought about. The current version (TEMPER v2.0) has been released in October 2007.
- Using TEMPER in 3 steps



SCENARIO SELECTION



SIMULATION PARAMETERS



POST-PROCESSING

Aim of the paper

- This paper details the ongoing work at CEG and SME/CRB to prepare the next version, which should be made available to MSIAC in late 2009, and give details on implementation procedures and coding strategies of interest for potential developers.
 - A companion presentation by P.-F. PERON will describe the work done at MSIAC to implement new models.



Simulation logic



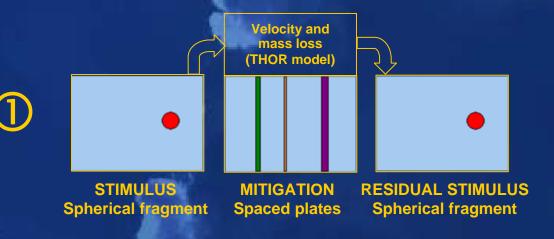
Conclusion

Hidden work

SNPE MATÉRIAUX ÉNERGÉTIQUES GROUPE SNPE

TEMPER: as simple as S / M / S

- TEMPER decomposes safety problems into the description of a Stimulus / a Mitigation / a Structure. The simulation then runs with one or more Model(s).
- The simulation logic relies on 2 steps :

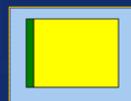


RESIDUAL STIMULUS
Spherical fragment

STRUCTURE Covered E.M.

MODEL V_{lim} Jacobs-Roslund









STIMULI

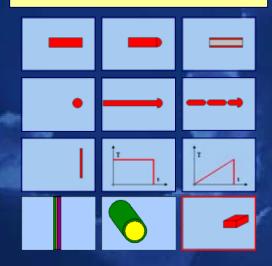
Flat end rod Round end rod Flat cookie-cutter **Spherical fragment** Simple shaped charge jet Real shaped charge jet Thin plate **Constant Temperature Rising Temperature Multilayer Impactor 1D** One on One Warhead **Parallelepiped Fragment**

MITIGATIONS

Air [modified] **Spaced plates** Single layer

STRUCTURES

Bare plane explosive Bare cylindrical explosive **Bare spherical explosive** Covered plane explosive **Multilayer Structure 1D**



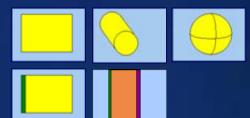
MODELS

V²d (Held) u²d (Held) **Ecrit Walker - Wasley Ecrit James**

Y (Yactor) [modified]

Vthreshold (Jacobs - Roslund) tcook-off (Creighton - Victor) **Ethreshold (Peugeot) BSDT** (Peugeot)

Godlag 1D (Baudin)



In RED: New in v2.0



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Object-Oriented Programming



- Linear programming
 - Basic variables (Int, Single, double, Char, ...) and arrays.
 - Input ⇒ Data processing ⇒ Output.
 - GOTO / GOSUB = almost impossible to debug and maintain.
 - For geeks and computer scientists! (one-liner contests, vi, ...)
- Structured programming
 - Complex variables (Recordset, List, ...).
 - The "main" program calls subroutines when necessary.
 - Easier to debug and partially reusable.
- Object-oriented programming
 - Objects are much more than variables: they have functions and procedures [methods] as well as variables [properties].
 - Program objects mimic real-life things, so their interactions and behaviours are easily understood.
 - Easy to debug and re-use.
- Design patterns in OO programming
 - Design rules to ease the interactions between objects (for instance the Model / View / Controller pattern).



TEMPER

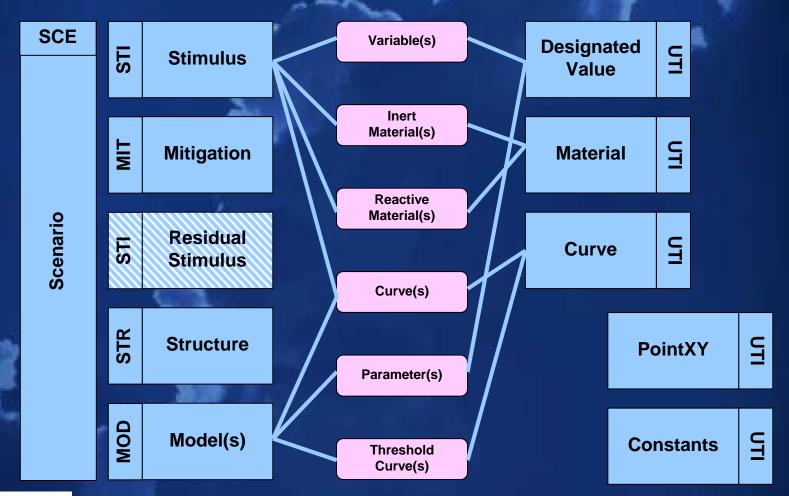
The objects model in TEMPER

(somewhat simplified ...)



OPT

Optimization





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SME/CRB Models



- SME/CRB: a new developer for TEMPER
 - The SME/CRB Research Center, among many other things, is developing ammunition safety models under DGA contracts.
 - Albeit only executables were required by DGA, SME/CRB proposed to share its sources with the community and to allow integration of their models in TEMPER.
 - Two of these models will be presented: SANDI for Sympathetic Detonation, which will be a second SD model, and INITHER for the 1D modelling of thermal initiation.
 - Details of these models will be released in MSIAC reports.





SANDI: SD model



Brief description

SANDI is a stand-alone program implementing the SME/CRB SD approach 1.

Example

- The test case consists of munitions filled with PBXN-109, with rubber liner and steel case, separated by an air gap and a steel barrier (mitigation).
- The fragment is a parallelepiped. Its mass is the largest fragment mass according to Mott equations for a 99% confidence level.
- Shock matching is computed for the residual fragment, and reaction is assessed by either a pressure or a pressure / time criterion.

Coding strategy for TEMPER

- SANDI is a relatively simple model, similar to the MSIAC NDI model. It will be handled in TEMPER as an
 internal model.
- The Initial Stimulus will be the "One On One Warhead", whereas the Residual Stimulus will be a "Parallelepiped Fragment", previously coded for the MSIAC NDI approach. The "Single Layer" and "Spaced Plates" Mitigations will be adapted to include the new interaction models.





[1] Annereau C., Lécume S., "Modélisation Analytique d'Apparition ou Non d'Une Détonation par Influence", EUROPYRO 99.

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INITHER: 1D thermal model



Brief description

- INITHER is an 1D finite element thermal code developed by SME for SCO and FCO.
- INITHER computes thermal exchanges (conduction, convection, radiation) from the outside stimulus to the energetic material through layers of materials in 1D cylindrical geometry.
- The heat equation is solved in each element by the method of Crank-Nicholson. The reaction kinetics is a three stages Arrhenius.

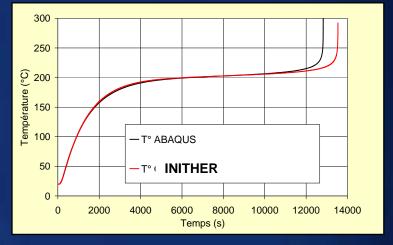
Example

 A comparison with ABAQUS is given for the heating of a propellant cylinder having an OD of 50 mm.

ρ= 1820 kg/m3	Cp= 1133 J/(kg.K)	a= 3,627E-07 m2/(s.K)
Z1= 14,31538 s 1	EA1= 12344,867 K	Q1= 57304280 J/m3
Z2= 32,302542 s 1 Z3= 32,328255 s 1	EA2= 20827,813 K EA3= 20731,82 K	Q2= -596543500 J/m3 Q3= 8486248000 J/m3

Coding strategy for TEMPER

INITHER is a more complex model dealing with 1D cylindrical multilayer structures. The
model requires time and space discretizations, matrix inversions, etc. To avoid
unacceptably long running times, it has been decided to call INITHER as an external
executable, using a similar procedure than for GODLAG.





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How to include a model?



The coding of models is less straightforward than for S/M/S objects, but still relatively simple.

The best way to code a model is to write down equations first, and to wonder how to use existing Stimulus and Structure objects to describe their interactions. It is often possible to re-use part of the code written for similar models (for instance all shock matching for analytical SDT models, a.s.o.).

- The common structure for Model object classes is as follows:
 - "Declaration" part [properties, coded once for good]
 - Definition of private "properties" (variables or objects).
 - "Interface" part [access to properties via methods, coded once for good]
 - Allows other objects to access private properties through a controlled channel.
 - The OO way is through "Property Get" and "Property Let/Set" methods.
 - "Common" part [fixed methods, coded once for good]
 - CheckReactiveMaterialParametersOK.
 - "Adaptable" part [methods modified by the developer]
 - Initialize.
 - Execute (modified only for external models : see GODLAG / INITHER for instance).
 - ComputeThresholdCurves.
 - ReactionDiagnosisPoint (sets the Residual Stimulus on the proper plane).
 - ReturnYFromX, ReturnXFromY (if required): gives the ordinate of a point on a threshold curve with a given abscissa (or the inverse).
 - CompatibilityRules

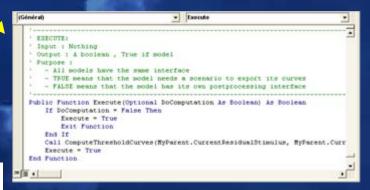


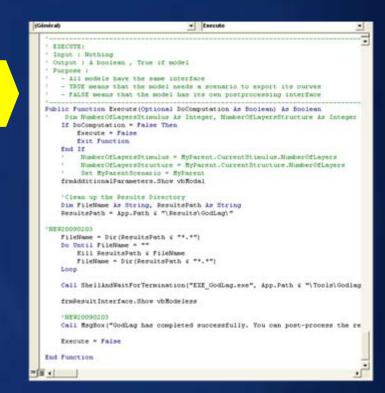
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External models



- The « Execute » method:
 - In TEMPER v2.0, we introduced the possibility to call external programs for complex models. It had already been done for GODLAG, a 1D multi layer shock propagation hydrocode. TEMPER doesn't really make distinctions between internal and external models. The embedding of external models is done through the "Execute" procedure of the Model object class.
 - For simple models, the "Execute" procedure is always the same (picture below).
 - For external models this "Execute" procedure becomes more complex, since it may call specific User Interfaces for both the introduction of additional parameters (time limits, sensors, etc.) and the post-processing of results (right).









User-oriented developments



Bug corrections and Requests for enhancements

- The first TEMPER training session has been held in Paris at the beginning of 2009. It was an unique opportunity to discuss with French users. A number of small bugs or requests have been reported and are currently under correction or development.
- We will do our best to include also in the next release all the bug corrections and (minor!) requests for enhancements that will arise during the 2009 international training sessions (during the present IMEMTS and/or ICT conference).

"It's impossible to make anything foolproof, because fools are so ingenious ..."

Better error handling

- TEMPER is not error proof and ends sometimes abruptly :
 - Input data check has to be improved.
- Needs for a systematic Error handling, using Error classes and events.

Better unit management

- UTI_DesignatedVariable could be updated to really handle conversions.
- Still a problem for parameter-dependent units (K = Pⁿ.t for instance).
- Switch to non-dimensional variables as often as possible.

Improvement of the online help

- Systematic link to MSIAC reports.
- Inclusion of Flash tutorials (Wink or CamStudio capture softwares)



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Pending questions



Programming language

- **VB 6.0** is not supported anymore.
- "Free" languages may be interesting: Java, Free Pascal, Python.
 - · Some of them are multi-platform.
 - Some of them suffer from drawbacks (poor string functions, limited OO, ...).
 - Limited OLE support.
 - A huge work is required to recode TEMPER ...
- VB.NET, if not free, has a free Express Edition.
 - Some work is required, since OO is much more drastic than in VB 6.0
 - Express Editions are frequently updated.
- **Embedded Excel workbook: pros and cons**
 - It's nice to have Excel in TEMPER:
 - Post-processing of TEMPER results is immediate.
 - **TEMPER benefits from Excel possibilities (multi-sheet, charts, etc.)**
 - But the object library in Excel changes frequently and is unstable:
 - Sometimes we loose VBA string functions (documented bug, no solution).
 - TEMPER won't run with Excel 2007 (OLE support ?).
 - Alternatives are:
 - Combined VB MSFlexGrid and MSChart controls.
 - **OLE link to an OpenOffice workbook.**





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Conclusion



Also on our roadmap

- New projectile (conical tip) and projectile/structure interactions (modified models):
 - MSIAC development : see companion presentation by Pierre-François Péron
- DDESB blast wave tool.
 - Eric J. Deschambault and Michael M. Swisdak kindly allowed us to introduce the DDESB bare explosive / open air fits in TEMPER.
 - This tool could be used to compute a blast from a « Bare Charge » stimulus and subsequent reaction thresholds, or just to determine blast wave parameters in Air (Mitigation) at different distances.
 - For more complex simulations, the DDESB « Blast Effect Computer » is a valuable and straightforward tool!

TEMPER availability

- Users and developers are neither within the same location nor within the same organization. In order to provide to the community a common tool that could become a reference in the S3 community, it had been decided to create a TEMPER e-working group with MSIAC as a focal point.
- Experts interested in the project can participate using the web at two levels:
 - The users level, i.e. experts that use TEMPER, provide the group with some feedback, new parameters but also with new ideas/requirements.
 - The developer level, i.e. super users that also use this platform to develop models and share the newly implemented models but not necessarily the parameters coming with.
 - Please contact MSIAC if you are interested to join us!







TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Analyzing Production Processes of Energetic Materials using Ultrasound Technology

Presented by: Rajen Patel Contributors: Sean Swaszek, Wes Cobb

May 11th-14th, 2009

NDIA IM/EM Symposium rajen.b.patel@conus.army.mil





Ultrasound is being used in the following applications at ARDEC

- Melt Cast Analyzer
- Press Analyzer
- Primer Press Analyzer

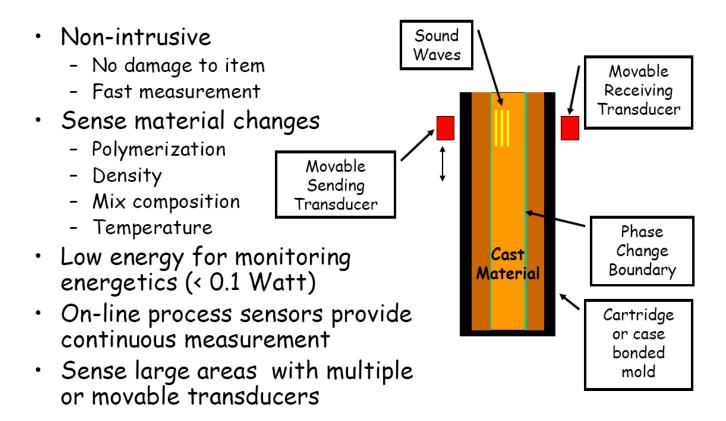
Ultrasound Technology has proven to be highly viable for characterization

- Extensive amount of information available
- Can be obtained Real Time
- Low Energy, safe for operators and explosives
- Easily pass through metal



Ultrasound Melt Cast Analyzer





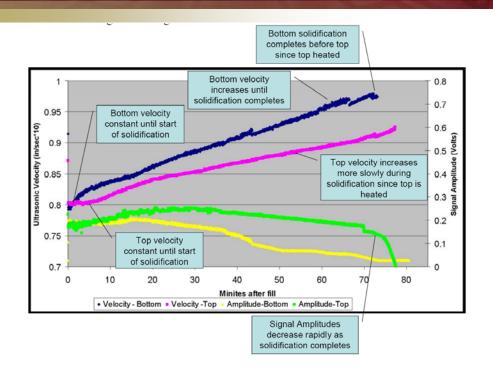


Ultrasound Melt Cast Analyzer

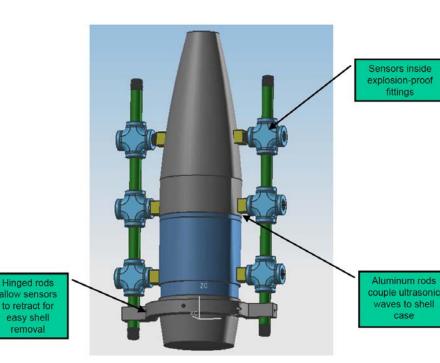
easy shell

removal





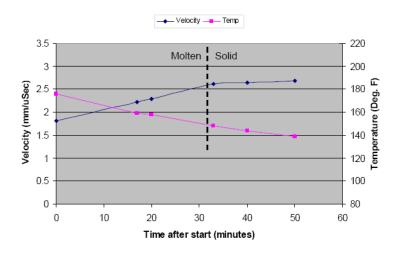
- Ultrasound can use attenuation to detect time of solidification throughout the munition.
- Ultrasound can also be used to detect settling



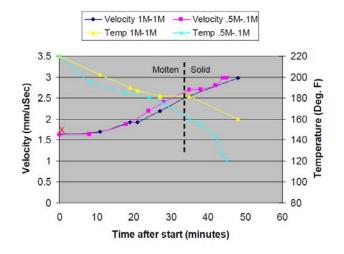


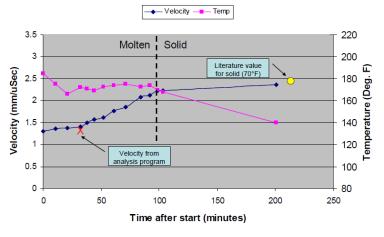
Results from Initial Tests of Equipment



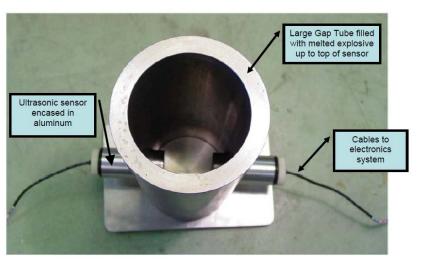


Plot of measured ultrasound velocity versus cooling time for comp B using 1MHz transmitter and receiver





Plot of measured ultrasound velocity versus cooling time for TNT using 1MHz transmitter and receiver

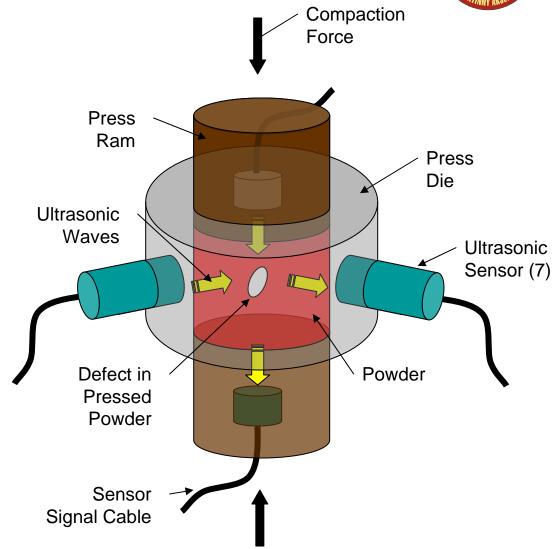




Ultrasound Large Press Analyzer



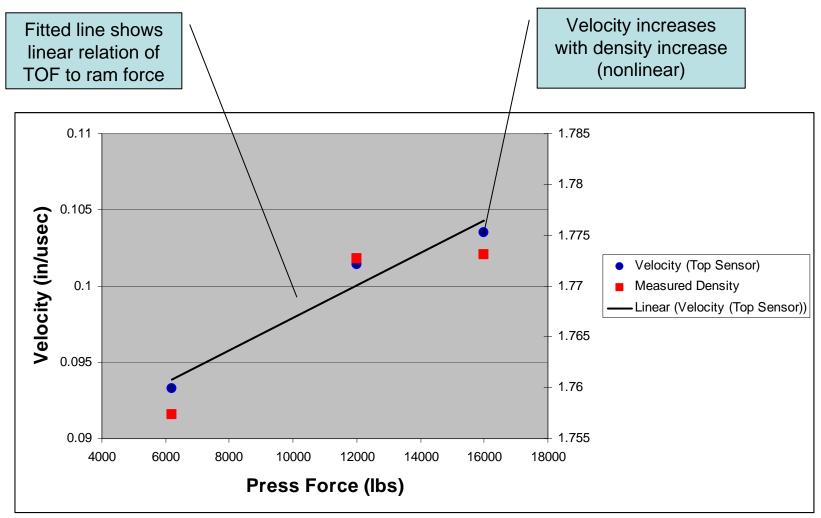
- Ultrasound technology will be added to Large Press
- Will detect voids and defects
- Will also be able to provide characterization such as mechanical properties





Velocity tracks density for PAX-2A billets



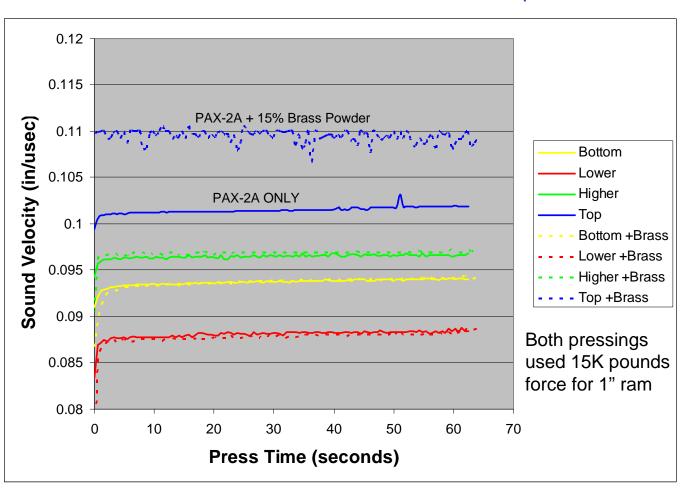




Press contaminant detection



Pure PAX-2A versus PAX-2A with 15% brass powder mixed in at top of billet



Results:

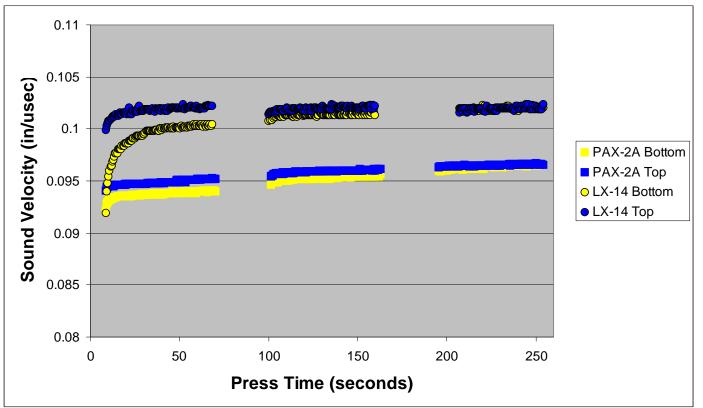
- 1. The two pressings are consistent except for sensor locations where brass is concentrated
- 2. The significant change in velocity may provide sensitive indications of contaminants or explosive material variations



Compaction in two different explosives







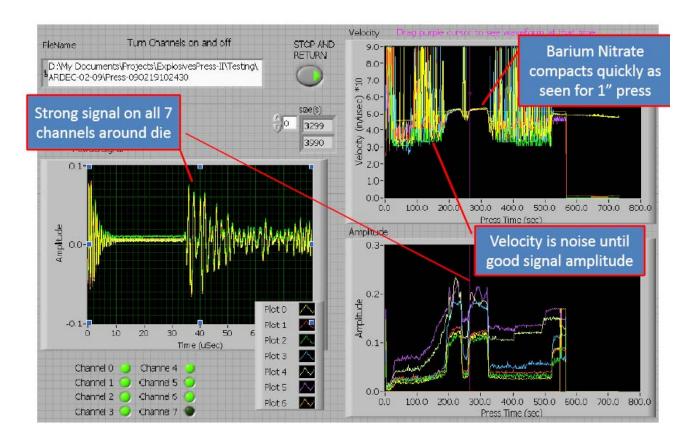
Results:

- 1. The bottom of the LX-14 billet takes much more time to compact than the top (may be due to increased binder in LX-14)
- 2. Much higher sound velocity in LX-14 is characteristic of the constituents of this material
- 3. PAX-2A compacts almost immediately compared to LX-14



Press Output Screen

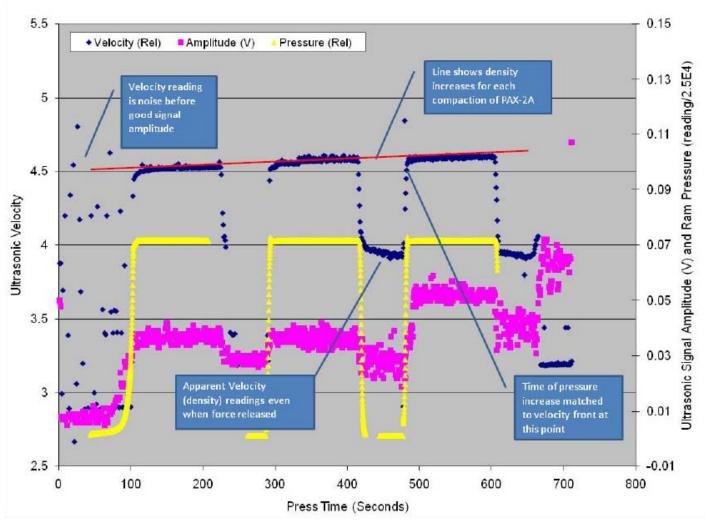






Results from Last Pax 2a Pressing







Ultrasound Primer Press Analyzer

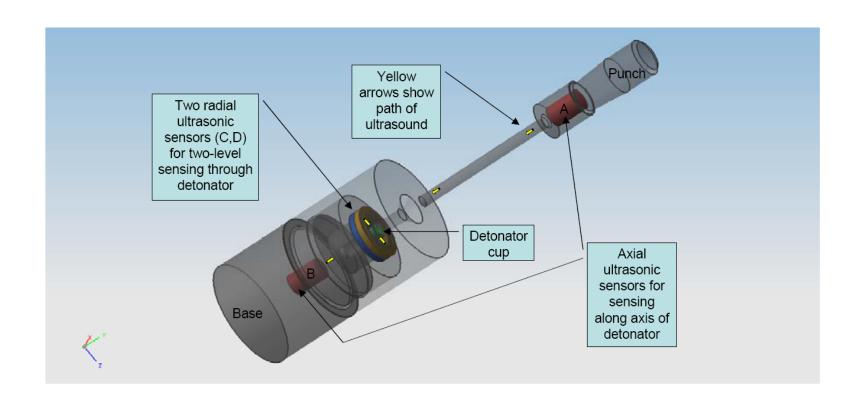


- Detonator project at ARDEC have some problems with inconsistency and quality in product
- Consistency and Quality can be improved with use of Ultrasound Equipment
- Major challenge is design of equipment which can fit small sizes



Ultrasound Primer Press Analyzer



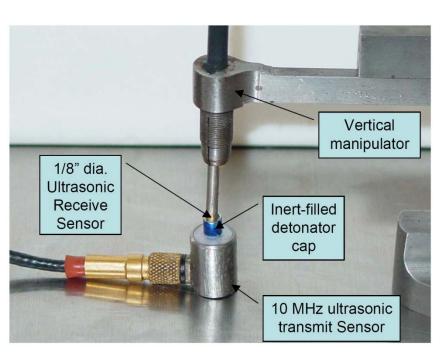


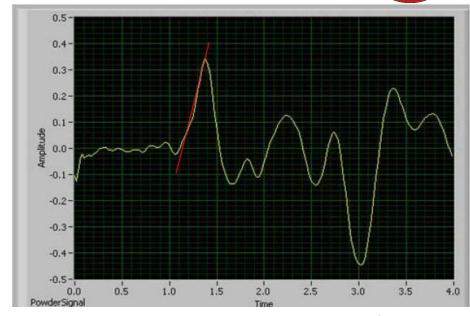


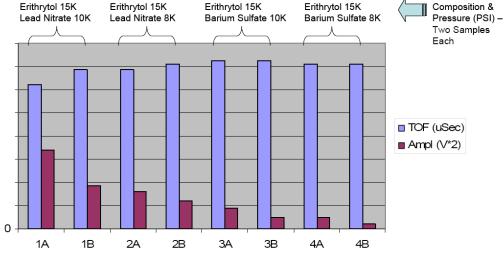
Ultrasound Primer Press Analyzer



- Initial feasibility study is good
- •Time of Flight and Amplitude can be detected through detonator





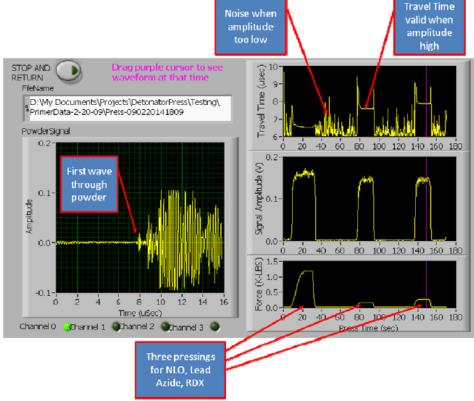




Primer Press Set Up and Output Screen



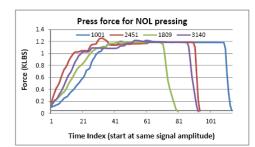


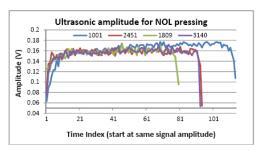


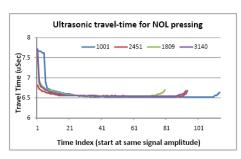


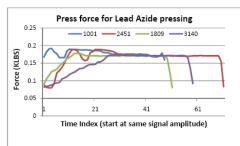
Results from Primer Press

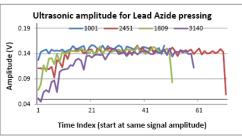


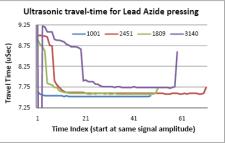


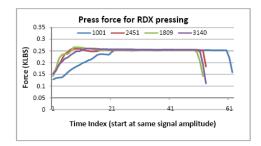


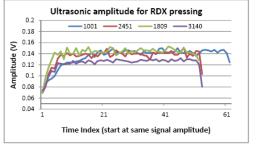


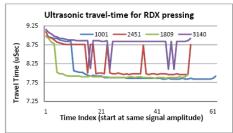














Other Areas of Interest



Proven that Ultrasound Applications exist in the following

- Viscosity Detection
- Water Content Analyzer
- Advanced Characterization of Aging
- Acoustic Sensing of Combat Threats
- Detection of Closed Cracks in Explosives
 Ultrasound at ARDEC is currently pursuing 3 main efforts:
- Ultrasound Large Press Analyzer
- Ultrasound Melt Cast Analyzer
- Ultrasound Primer Press Analyzer



Acknowledgements



- Phil Samuels
- Erik Boykin
- John Centrella
- Nick Guerra
- Emily Cordaro
- John Centrella
- Garrett Rector
- Joe Christiano
- Daniel Stec



South African Navy Prioritizing of Munitions for Insensitive Munitions Characterization

Presented by Captain N.P.J. (Klaas) Steyn

Inspector Naval Ordnance South African Navy





Need for Prioritization Method

- Department of Defence Policy Guideline
- Limited IM-budget
- Phased approach
- Prioritize munitions
- No methodology 100⁺ munitions items
- Challenge to differentiate priorities





Development of Methodology

Scheduled specialist workgroup

- 2 days at Rheinmetall Denel Munition
- Goal to prioritize SA Navy's munitions
- No methodology to use at workgroup
 - Brainstorm, subjective argumentation





Development of Methodology

- · Challenge of methodology remained
- Spent weeks contemplating
- Realised only objective way was to create a "Value System"
- Took Value System to workgroup





Development of Methodology

- About 80% of SA's IM specialist present at workgroup
- Buy-in to idea of Value System
- Value System parameters
 - Identify discriminatory Criteria
 - Preferably four to six criteria only
 - · Relative Weighting of criteria
 - Objective scoring method





Acknowledgement

- · Mr Cedric Brijraj co-facilitator
- Participants (20+) of workgroup from
 - Rheinmetall Denel Munition
 - Denel Dynamics
 - PMP
 - Armscor
 - SA Navy
 - 550 Mun





Development Process

- Brainstorm Criteria/Factors
 - 30+ factors identified
- Round Table discussion
 - Individual Input by each participant
 - Grouping of certain criteria
- Reduced list to 10 Criteria
 - Individual prioritization
 - Round table discussion





Development Process

- Individual ranking of Criteria
- Reduced to four main Criteria with two having sub-criteria
- Ranking of selected criteria
 - Each participant indicated suggested weighting per criteria
 - Weighting determined through averaging of individual weighting scores
- · Objective scoring value for Criteria



Selected Value System Criteria (Weighting)

Service Life Phase	(0,19)
Use Profile	(0,37)
Severity Of Consequence	(0,31)
Current IM Status	(0, 13)



Service Life Phase Weighting 0,19

Out of Service by 2010 :2

Out of Service by 2012 :5

Out of Service by 2016 :8

In Service beyond 2016 :10

* Calculation Example: Round 76mm HE





Use Profile Weighting 0,37

Factor of:

Deployment Exposure Risk (0,5) and Quantity Carried Onboard (0,5)



Use Profile: Sub-criteria 1 Deployment Exposure Risk

Always carried onboard

Always between decks:

Upperdeck routes/stowages: 10

Only carried onboard during specific exercises:

Always between decks: 4

Upperdeck routes/stowages: 6





Use Profile: Sub-criteria 2 Quantity Carried Onboard

< 10 items/units :3
10 - 25 items/units :5
25 - 75 items/units :7</pre>

> 75 items/units



:10



Severity of Consequence Weighting 0,31

Factor of:

NATO HD Classification (0,5)

and

Net Explosive Content (0,5)





Consequence: Sub-criteria 1 NATO HD Classification

1.1 Mass Explosion	:10
1.2 Projectiles, mass explosion	: <i>8</i>
1.3 Flame & Fire, minor projectile	: 5
1.4 No reaction outside packaging	:2



Consequence: Sub-criteria 2 Net Explosive Content

```
< 750g : 1

750g - 5kg : 3

5kg - 12kg : 6

12kg - 100kg : 8

> 100kg : 100
```



Current IM Status

Weighting 0,13

No THA or IM-testing :10
THA completed (manual process) :7
THA completed (Software) :5
STANAG 4439 tested :3
THA and STANAG 4439 tested :1



Calculation Example Round 76mm HE

```
Service Life (0,19): Out of Service by 2016 = 8
Use Profile (0,37):
  Exposure Risk: Always between decks =
                                              8
  Qty Onboard: >75 items/units =
                                              10
                           (8*0.5) + (10*0.5) = 9
Severity of Consequence (0,31):
  HD Class: 1.1 Projectiles
                                     10
  NEC: 750g - 5kg
                          (10*0,5) + (3*0,5) = 6.5
IM Status (0,13): THA & IM testing =
```

Rank Score Calculation (with weighting):

8(0,19) + 9(0,37) + 6,5(0,31) + 1(0,13) =

6.995

Sample Rankings of Munitions

Rank Score	Ammunition Type	Service Life	Use Profile	Qty	HD	NEC	IM Status
8.605	Round 35mm HEI	2016 >	Upperdeck	> 75	1.2	750g – 5kg	Nil
8.325	Missile SSM	< 2016	Upperdeck	< 10	1.1	> 100kg	Nil
8.140	Round 35mm PracT	2016 >	Upperdeck	> 75	1.3	750g – 5kg	Nil
8.050	Charge Dems 450g	2016 >	Upperdeck	25<>75	1.1	< 750g	Nil
8.005	Missile SAM	2016 >	Inboard	10<>25	1.1	12kg-100kg	THA
7.915	Rnd 20mm HEIT	< 2016	Upperdeck	> 75	1.2	< 750g	Nil
7.855	Fuze Prox 76mm	< 2016	Inboard	> 75	1.1	< 750g	Nil
7.855	Rnd 76mm SUPrac	< 2016	Inboard	> 75	1.2	750g – 5kg	Nil
7.450	Rnd 20mm PracT	< 2016	Upperdeck	> 75	1.3	< 750g	Nil
7.215	Torpedo Combat	< 2016	Spec- Inboard	< 10	1.1	> 100kg	Nil
6.995	Rnd 76mm HE	< 2016	Inboard	> 75	1.1	750g – 5kg	IM-t
6.445	Mine Combat	< 2010	Upperdeck	< 10	1.1	> 100kg	Nil



Conclusion

- · Value System proofed very effective
- Other arms of service (Army & Air Force) will adopt and use to prioritize their munitions
- Available for other Armed Forces that may be interested (adopt and adapt)



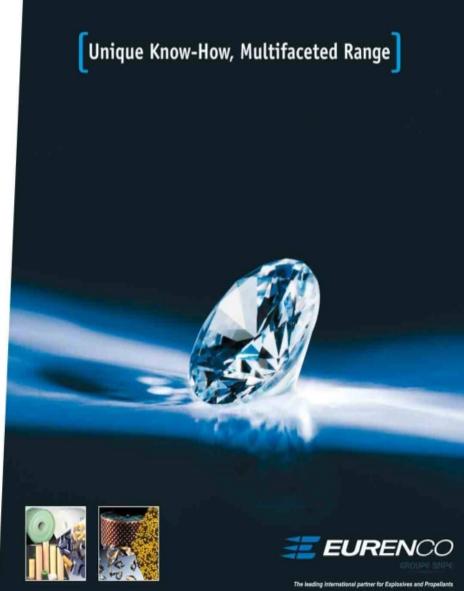


The leading international parmer for Explosives and Propellants

A new generation of binder for cast PBX

B.Mahé, EURENCO

B. Le Roux, SME







► <u>Eurenco and Cast-cured PBX</u>

- © EURENCO, a subsidiary of SNPE Matériaux Energétiques has a long history of promoting cast-cured plastic bonded explosive technology
- First productions began at Sorgues plant in 1974 at industrial scale
- **EURENCO** has
 - -all equipements necessary for production according to batch process
 - -developed and a patented worldwide new process for loading small items (shells)
 - -a large catalogue of formulations qualified according to STANAG 4170





➤ STANAG 4170-qualified compositions

	Binder	HMX	RDX	NTO	PETN	AP	AL	Main applications
ORA86B	Inert	V						Missile WH – Shaped charge
HBU88B	Inert		V					Mortar and shells – WH
B2238A	Inert		V					Booster – WH – Shells
B2188A	Inert	V			V			Booster – SCO Safety Device
B2214B	Inert	V		V				Penetrators – Missile WH
B2211D	Inert		V			V	V	Underwater torpedoes/mines
RH26-2	Inert		V					Shells
PBXN-110	Inert	V						Missile WH – Shaped charge
PBXN-109	Inert		V				V	GP bombs, Heavy penetrator
B3108B	Energetic	$\overline{\mathbf{V}}$					V	Missile WH – enhanced blast





Cast-cured PBX

```
A binder
        Prepolymer (HTPB - PU – PE - ....)
        Curing agent (IPDI - MDCI - ....)
        Plasticizer (DOA - DOZ - IDP - ....)
        Additives (processing aid – anti oxidant – catalyst)
Explosives fillers
        I-RDX®
        RDX
        HMX
        NTO .... depending of required performances
```





► How to improve performances

Energetic binder

B3108B: polyester plasticized by nitrated oil (NGl and BTTN)

limited industrial application due to mandatory specific installations (synthesis and handling of nitrated oil)

still used at the industrial sacle for specific application (high performance missile warhead)

Powerful explosive filler

B2266A: CL20 (laboratory scale)

no industrial application due to the very high cost of raw materials





Higher filler content

HBU88B: 88% I-RDX®

PBXN-110: 88% HMX

limitation due to process constraints:

viscosity (< 5 kpoises) pot life (> 6 hours)

Feasible by

- -increasing the platicizer content
- -optimizing grain sizes for the explosives
- -adding specific processing aids

wusing a lower viscosity prepolymer





> HTPB

HO
$$CH_2$$
 CH_2 CH_2 CH_2 CH_3 CH_3 CH_4 CH_5 CH_5

R45HTLO

density 0.90

molecular weight 2 800

viscosity 50 poises

hydroxyl value 0.83 meq/g

moisture content 0.05 %





> HTPB

HO
$$CH_z$$
 CH_z CH_z

R45HTLO		R20LM
density	0.90	0.90
molecular weight	2 800	1 220
viscosity	5 000 mPa.s	19 poises
hydroxyl value	$0.83 \ meq/g$	1.7 meq/kg
moisture content	0.05 %	0.05 %

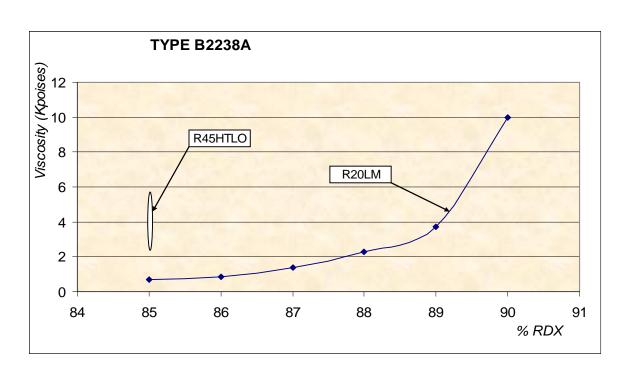




B2238A as a reference formulation:

HTPB polymer

crude RDX : 85 → 89 %

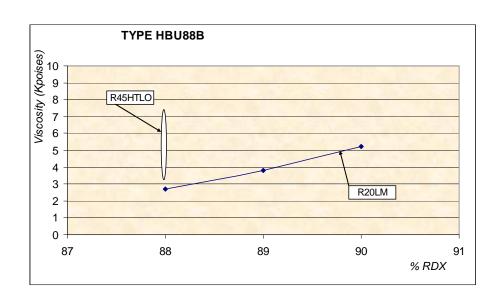






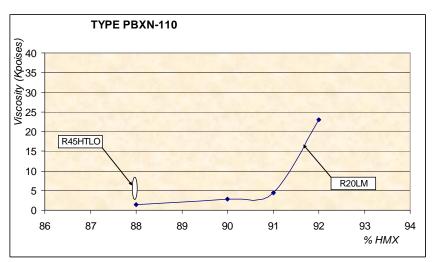
B2263A (HBU88B) as a reference

HTPB polymer I-RDX[®] 88 → 90 %



PBXN-110 as a reference

HTPB polymer
HMX 88 → 91 %







Two new formulations have been defined and scale up to the industrial scale

B2265A (HBU90): 90 % I-RDX®

B2273A (OCTABU90): 90 % HMX

Performances and physical properties, IM characteristics were determined

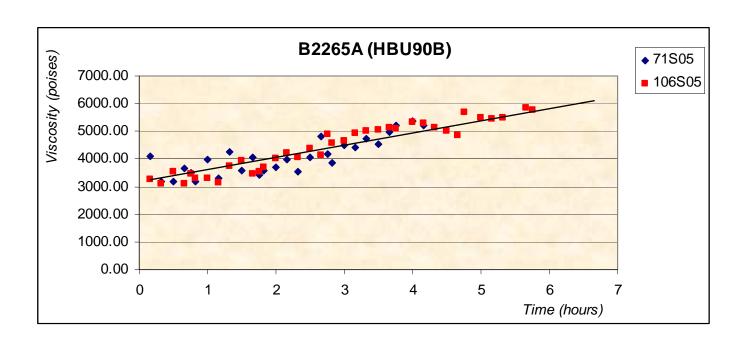
Their qualifications according to STANAG 4170 were carried out







Viscosity









Performances & Physical properties

	B2263A (HBU88B)	B2265A (HBU90A)
Ingredients		
PBHT I-RDX®	R45HTLO - 12% 88%	R20LM - 10% 90%
Density	1.62	1.65
Detonation velocity (m/s)	8 180 m/s	8 290 m/s
Pcj Mbar (calculated)	0.271	0.283
Mechanical properties(tensile) - 45°C Sm (stress) em (strain)	3.0 MPa 9.9 %	2.5 MPa 3.1 %
+ 20°C Sm (stress) em (strain)	1.05 MPa 10.6 %	0.91 MPa 4.5 %
+60°C Sm (stress) em (strain)	0.73 MPa 8.4 %	0.65 MPa 3.6 %
+70°C Sm (stress) em (strain)	/ /	0.56 MPa 3.2 %

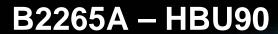


B2265A - HBU90



Ageing

	TO)	T0 + 6months a	at 60°C
Temperature test	Sm (MPa) em (%) Stress Strain		Sm (MPa) Stress	em (%) Strain
-45°C	2.5	3.1	2.77	4.8
+20°C	0.91	4.5	0.99	4.0
+70°C	0.56	3.2	0.57	3.3







Safety properties

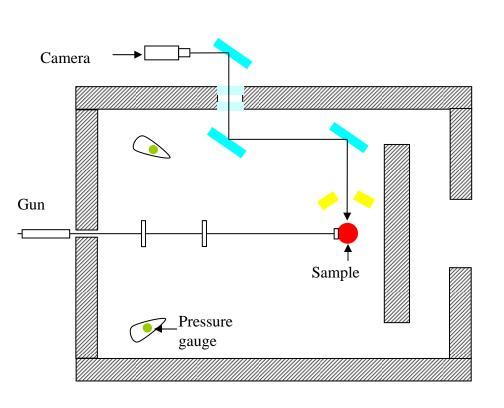
	B2263A (HBU88B)	B2265A (HBU90A)
Ingredients PBHT I-RDX®	R45HTLO - 12% 88%	R20LM - 10% 90%
Shock sensitivity (BAM test)	24 J	35 J
Friction sensitivity (BAM test)	23+/30 at 353N	11+/30 at 353N
Shock sensitivity (30 Kg fall hammer)	$HLNR \ge 4 \text{ m}$ $HLNP \ge 4 \text{ m}$	$HLNP \ge 4 \text{ m}$ $HLNR = 3.75 \text{ m}$
Gap Test (acetate cards) (STANAG 4488 Annex B)	150	155
Self ignition temperature	209 °C	210 °C
Long term cook-off temperature	126 °C	123 °C







Bullet impact (12.7 AP)





Steel cylinder:

3 liters content

Breakup pressure: 25 to 30 MPa

Explosive to test:

Ø 123 mm

H 240 mm



B2265A - HBU90



12.7 AP : 450 m/s
No reaction



12.7 AP: 890 m/s
Reaction after 5 minutes
all product burnt





12.7 AP: 550 m/s
Pneumatic explosion after 20 minutes
31 % product recovered



12.7 AP: 1150 m/s
Reaction after 5 minutes
all product burnt



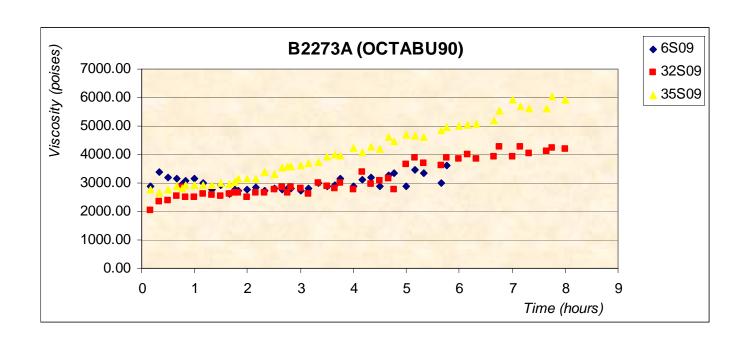




B2273A – OCTABU90



Viscosity





B2273A – OCTABU90



Performances & Physical properties

	<u>PBXN-110</u>	B2273A (OCTABU90A)	
Ingredients	R45HTLO - 12%	R20LM - 10%	
PBHT	88%	90%	
HMX			
Density	1.685	1.715	
Detonation velocity (m/s)	8370 m/s	8 510 m/s	
Pcj Mbar (calculated)	0.295	0.310	
Mechanical properties (tensile) - 45°C Sm (stress) em (strain)	1.0 MPa 9.8%	2.1 MPa 6.3%	
+ 20°C Sm (stress) em (strain)	0.41 MPa 10.6%	0.68 MPa 9.0%	
+60°C Sm (stress) em (strain)	0.24 MPa 10.2%	0.62 MPa 7.6%	



B2273A – OCTABU90



Safety properties

	PBXN-110	B2273A (OCTABU90A)
Ingredients PBHT HMX	R45HTLO - 12% 88%	R20LM - 10% 90%
Shock sensitivity (BAM test)	36 J	49 J
Friction sensitivity (BAM test)	14+/30 at 353N	10+/30 at 353N
Shock sensitivity (30 Kg fall hammer)	HLNR $\geq 4 \text{ m}$ HLNP = 2.25 m	$HLNP \ge 4 \text{ m}$ $HLNR = 2.75 \text{ m}$
Gap Test (acetate cards) (STANAG 4488 Annex B)	170	180
Self-ignition temperature	229 °C	243 °C



B2273A - OCTABU90



Bullet impact

12.7 AP : 450 m/s
No reaction



12.7 AP : 550 m/s
No reaction



12.7 AP: 870 m/s
All product burnt
during 15 minutes



12.7 AP: 1140 m/s
All product burnt
during 15 minutes







SUMMARY

- Poly Bd® R20LM is a HTPB with a low molecular weight and a low viscosity
- when used to prepare a cast cured PBX (instead of PolyBd®R45HTLO), the viscosity of the paste is significantly decreased. That allows to increase the percentage of the filler content
- * two formulations containing 90 % of I-RDX ® and 90 % of HMX have been developped, characterized and transferred at the industrial scale
- detonation performances are increased about 5 % in comparison with HBU88B and PBXN-110
- main safety and IM characteristics are maintained, especially a very good behavior under bullet impacts
- B2265A is qualified by the French MOD according to the STANAG 4170
- B2273A qualification is in progress





Thank you for your attention





Evaluation of R8002, an Alternate Energetic Plasticizer to BDNP A/F, for use in DOD munitions

Prepared by:

Lilia Mastov Fee lee

Presented by: Mica Mc Ghee-Bey

2009 Insensitive Munitions and Energetic Materials Technology Symposium

May 13, 2009





Objectives

- Evaluate alternate energetic plasticizer to BDNP A/F for use in DOD munitions
- Possible candidate: R8002-Energetic Plasticizer, being developed by BAE at Holston AAP
- Test, evaluate, characterize and compare PAX-3 explosives formulated with R8002 and BDNP A/F





Background

- BAE has performed some preliminary studies, using PAX-2A as the vehicle formulation to evaluate alternative energetic plasticizer R8002 (50% of 2,4-dinitroethylbenzene and 50% trinitroethylbenzene by weight).
- HSAAP has the technology and capability to produce this material in small quantities.
- Some work has also been done with cast-cure thermobaric explosive YJ05 using R8002 at Ensign-Bickford Aerospace and Defense.





Materials

BDNP A/F

- BDNP A/F is an energetic Plasticizer: 50% bis(2,2-dinitropropyl) acetal (BDNPA) and 50% bis(2,2-dinitropropyl) formal (BDNPF) used in various DOD propellant and explosive formulations (LOVA propellants, Navy PBX 106 Formulations, IM Explosives: PBXN-106, PAX-2A and PAX-3)
- First Manufactured by U.S. Navy (Indian Head) and Aerojet in the 1960's
- Later manufactured by Thiokol in the 1990's

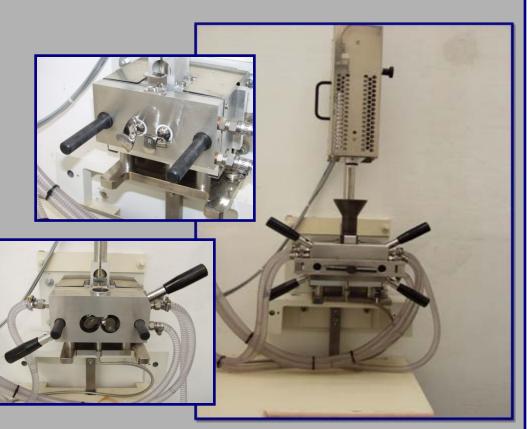
R8002

- R8002 is a 50:50 Mixture of Dinitroethylbenzene (DNEB) and Trinitroethylbenzene (TNEB)
- R8002 is similar to K10 (65:35 DNEB:TNEB)
- R8002 used in international formulations development efforts
- Synthesis routes developed by OSI scientists



Instruments





Thermo Haake Poly-Lab 300p System

Torque Rheometer

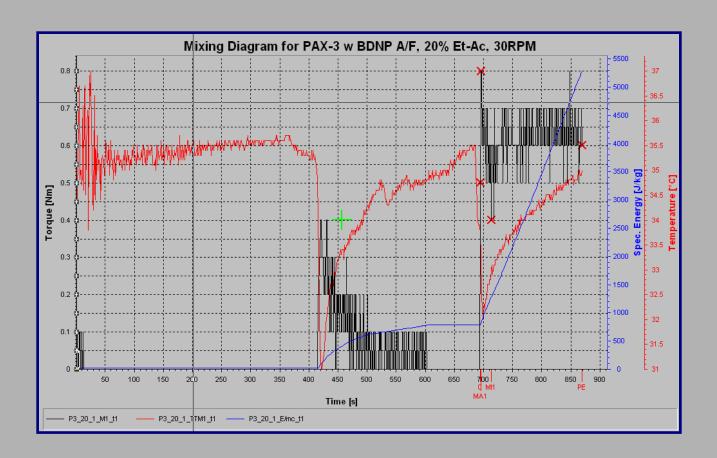
- Investigate mixing protocols for multicomponent systems to achieve optimum conditions for homogenization of end products.
- Study the mixing characteristics of energetic mixtures under different conditions (blade type, temperature, rpm, mixing time)
- Prepare new formulations that can improve the performance of existing materials.
- Evaluate material response during mixing.
- Provide homogeneous mixture for rheological analysis.
- Measures the following:
 - ✓ Dynamic viscosity depending on shear load
 - ✓ Melt behavior in the extruder
 - ✓ The influence of additives
 - ✓ Temperature and shear load behavior
- PolyViewTM software
- Specific energy input (SEI) is readily obtained for mixing.







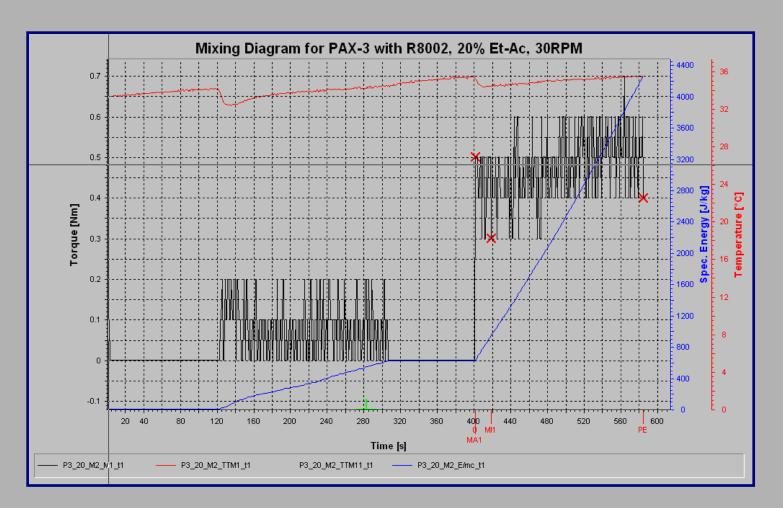
Sample Preparation







Sample Preparation







Instruments (cont'd)



Rheometric Scientific Dynamic Analyzer- RDA III

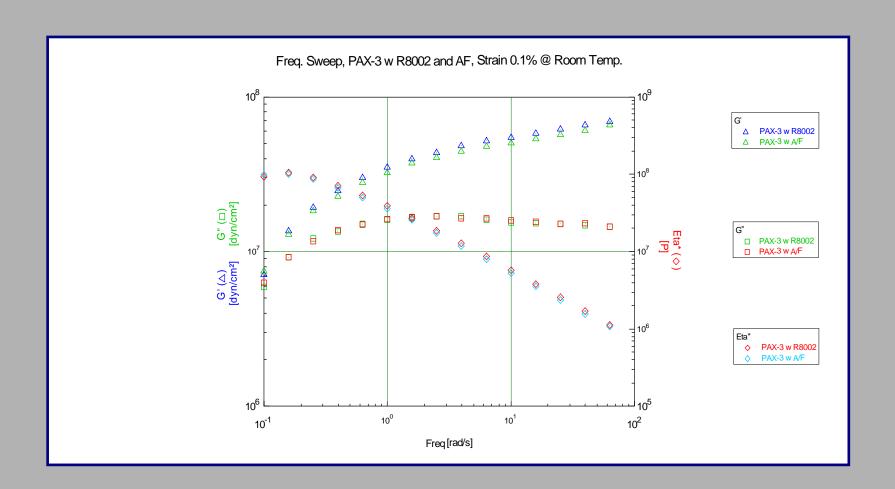
Dynamic Rotational Rheometer: RDA III

- Measure the properties related to the molecular structure of the polymers, such as molecular weight and molecular weight distribution.
- Measure the viscoelastic behavior of materials using dynamic mode.
- Measure the curing kinetics in a real time fashion of dynamic systems that can lead to optimizing the handling such materials.
- Serve as a tool for quality control for incoming and out-going materials.
- Assist in trouble-shooting problems associated with off-specification materials.
- Measures both dynamic and steady shear viscosities of energetics.
 - Measure dynamically the low temperature performance of materials as related to its glass transition temperature to evaluate performance of newly developed energetics.
- OrchestratorTM software





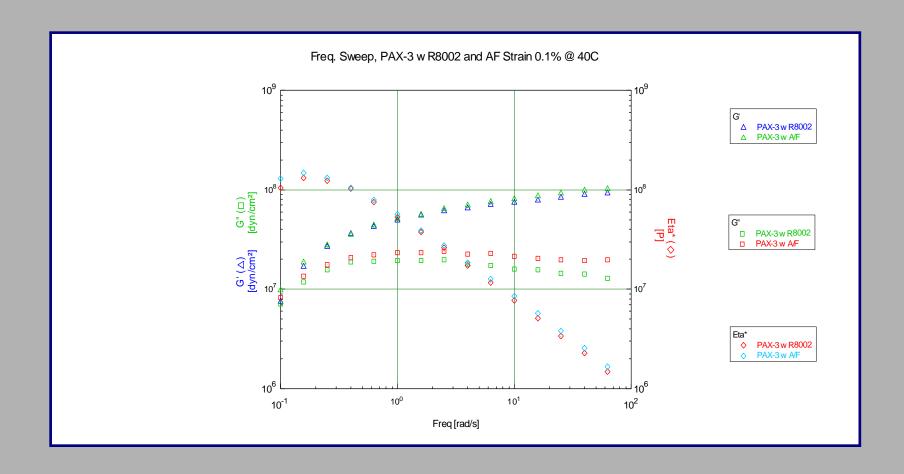


















		BDNP A/F-based PAX-3		R8002-based PAX-3		
Temp °C	Frequency rps	%Solvent	Complex Viscosity, Pa.S	%Solvent	Complex Viscosity, Pa.S	
Condition 1						
RT	1	16.73	7,340,000	15.30	5,256,700	
RT	1	16.16	3,268,400	15.96	5,743,100	
RT	1	15.93	5,692,600	15.67	5,240,000	
RT	1	15.49	6,254,100	16.07	7,176,900	
RT	1	14.55	8,038,700	15.06	8,017,200	
RT	1	15.16	4,722,100	15.33	5,674,100	
RT	1	16.83	8,475,200	14.66	5,886,200	
RT	1	15.57	4,827,600	15.75	6,134,400	
Condition 2						
RT	5	16.35	2,112,300	14.90	822,990	
RT	5	15.56	1,452,300	14.12	1,267,200	
RT	5	15.56	2,247,700	14.76	328,830	
RT	5	16.61	2,018,300	13.97	1,011,300	
RT	5	15.71	2,027,900	14.56	1,178,000	
RT	5	15.49	2,059,300	14.40	829,880	
RT	5	15.64	2,322,600	12.63	940,120	
RT	5	14.06	2,321,400	13.43	1,103,800	
RT	5	16.16	1,607,000			

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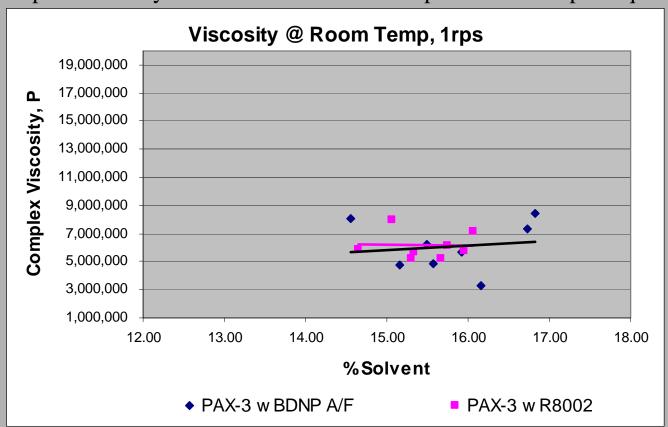
		PAX-3 w BDNF	A/F	PAX-3 w R8002	2
Temp °C	Frequency rps	%Solvent	Complex Viscosity, Pa.S	%Solvent	Complex Viscosity, Pa.S
Condition 3					
40	1	16.62	10,191,000	14.43	5,500,200
40	1	15.94	7,788,100	14.83	2,984,100
40	1	17.29	12,936,000	14.15	2,783,800
40	1	17.08	6,100,500	15.13	3,237,100
40	1	16.50	9,382,400	14.16	2,761,600
40	1	16.11	9,451,300	14.37	3,572,700
40	1	16.53	5,917,400	13.79	2,907,500
40	1	17.08	7,992,800	13.92	3,125,200
40	1	14.03	6,744,700		
Condition 4					
40	5	16.41	1,669,000	14.56	1,873,800
40	5	16.56	3,285,000	15.27	1,973,700
40	5	15.52	3,120,200	15.99	1,672,900
40	5	15.93	2,752,000	14.63	1,246,200
40	5	16.36	1,985,000	15.28	1,423,600
40	5	16.53	1,725,200	15.45	1,578,200
40	5	15.85	1,771,800	14.49	993,030
40	5	15.56	1,311,200	14.86	1,173,100
40	5	15.69	2,263,900		

Research, Development & Engineering COMmand





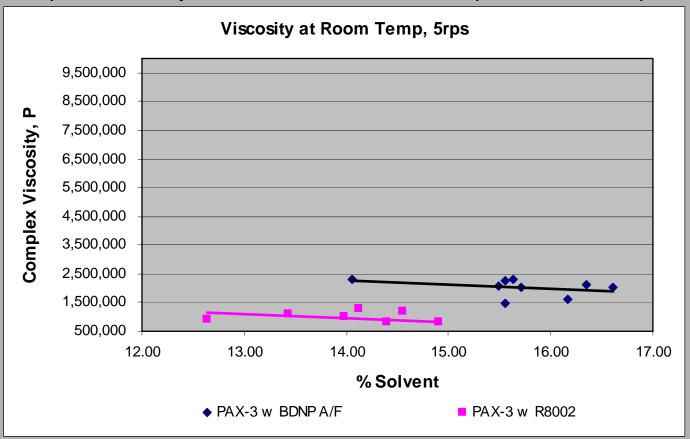
Complex viscosity vs. %Solvent @ room temperature and 1rps frequency.







Complex viscosity vs. %Solvent @ room temperature and 5rps frequency.

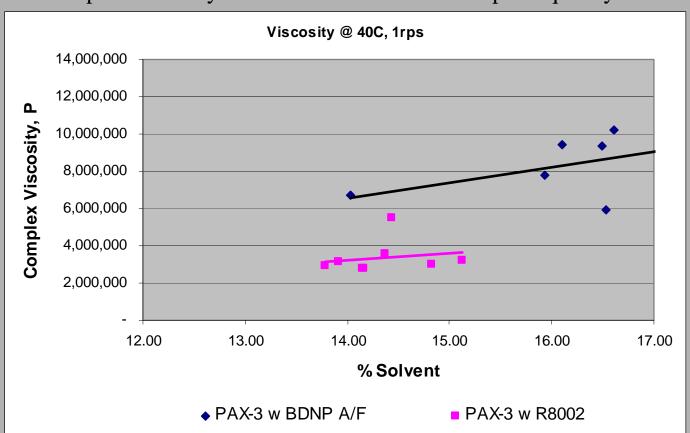


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Complex viscosity vs. %Solvent @ 40C and 1rps frequency.



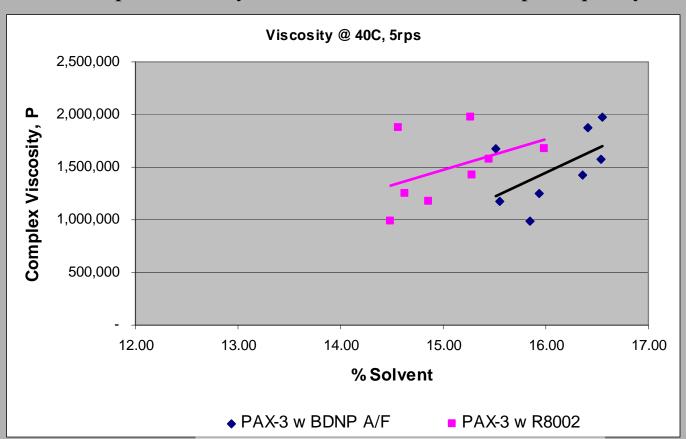
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Rheological Characterization

Complex viscosity vs. %Solvent @ 40C and 5rps frequency.



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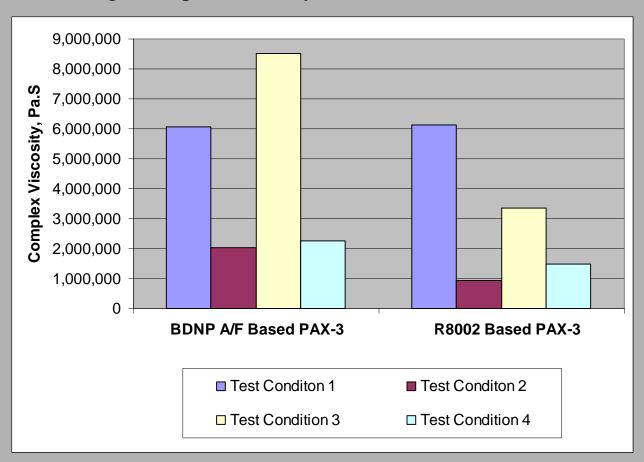






Rheological Characterization

Average Complex viscosity for the four test conditions.









Impact, Friction and Electrostatic Sensitivity Testing

	PAX-3 w BDNPA/F	PAX-3 w/R8002
Impact Sensitivity	Impact height 29.8cm	Impact height 28.7cm
Friction Sensitivity	reacted at a load of 288N and did not react in 10 trials at 240N	reacted at a load of 324N and did not react in 10 trials at 252N
Electrostatic Sensitivity	Did not react in 20 trials at 0.25 Joule (max. energy level)	Did not react in 20 trials at 0.25Joule (max. energy level)





Preliminary Conclusions

- R8002-based PAX-3 is more fluid than BDNP A/F-based PAX-3 under the same mixing condition which takes less effort to process during mixing and pressing operations.
- R8002 is comparable to BDNP A/F and is a less expensive alternate energetic plasticizer.
- BDNP A/F and R8002-based PAX-3's have identical density.
- R8002-based PAX-3 is 3.7 % more impact sensitive than BDNP A/F-based PAX-3.
- R8002-based PAX-3 is 11.1 % less friction sensitive than BDNP A/F-based PAX-3.





Planned Work

- Continue testing, evaluating, and comparing flow characteristics of BDNP A/F and R8002 based PAX-3.
- Perform additional mixing of both BDNP A/F and R8002 formulations PAX-3 for Press Tests.
- Perform Press Tests.
- Analyze Press Tests data.
- Incorporate Press Tests results into final report.
- Present recommendation.

FOX-7, an IM Ingredient Candidate – Where Are We Today?

Helena Bergman, Anna Pettersson and Henric Östmark, Swedish Defence Research Agency, FOI



Helen Stenmark and Carina Bergvall-Laitala Eurenco Bofors AB





Outline

- Why new Energetic Molecules
- FOX-7 Basics
- FOX-7 Crystals
- FOX-7 Formulations and Applications
- Conclusions

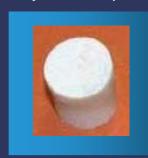


Ways to Insensitive Munitions..

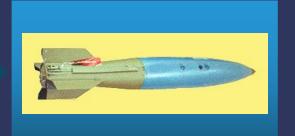
Modify the energetic material



Modify the composition



Modify the munition





Modify the ammunition depot or storage



Modify the packaging



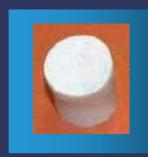
Ways to Insensitive Munitions...

Modify the energetic material



Modify the munition







FOI activities







Modify the packaging



FOX-7

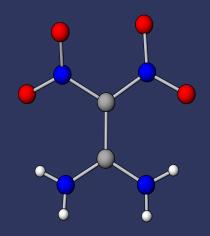
- 1,1-Diamino-2,2-dinitroethylene
- Developed at FOI in 1997---
- → WO Patent No. 9903818
- Produced by EURENCO Bofors AB under licence by Swedish Government

O NH
$$\frac{\text{HNO}_3/\text{H}_2\text{SO}_4}{5\text{-}10^{\circ}\text{C}}$$
 $\frac{\text{H}_2^+, \text{H}_2\text{O}}{\text{NO}_2}$ $\frac{\text{H}_2^+, \text{H}_2\text{O}}{\text{NO}_2}$ $\frac{\text{H}_2^+, \text{H}_2\text{O}}{\text{NO}_2}$ $\frac{\text{H}_2^+, \text{H}_2\text{O}}{\text{NO}_2}$ $\frac{\text{H}_2^+, \text{H}_2\text{O}}{\text{NO}_2}$



FOX-7 Basics

Low sensitivity explosives
Simple synthesis



Crystal Structure

Density (crist): 1.885 g/cm³

Heat of Formation: -32 kcal/mole

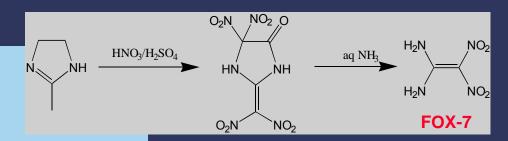
Sensitivity: drop weight 70 cm (RDX 38 cm)

friction > 350 N (RDX 120 N)

Explosion Temperature: 215 °C (RDX 220 °C)

Detonation Pressure (calc): 33.96 GPa (RDX 34.63 GPa)

Detonation Velocity (meas.): 8870 m/s (RDX 8930 m/s)



Synthesis

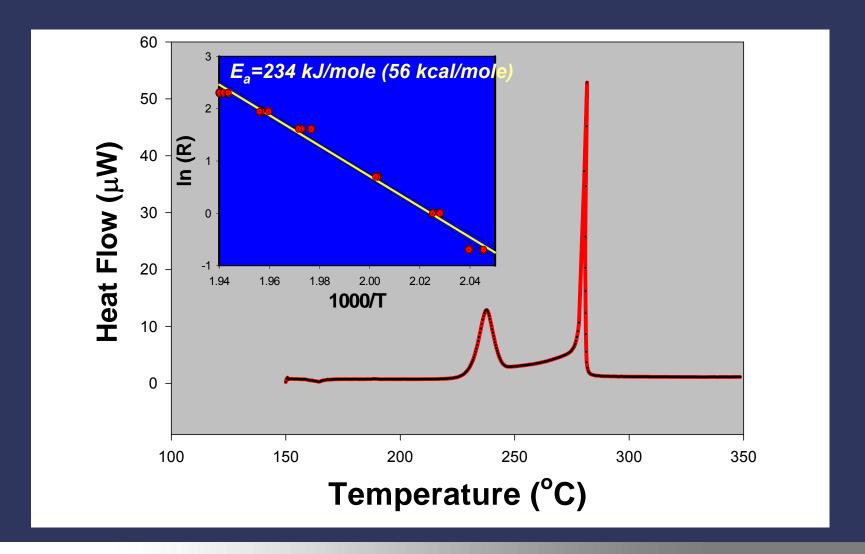


Impact and Friction Sensitivity of FOX-7

Sample	Drop height	Friction
	(cm)	(N)
FOX-7 (recryst., 250–355 µm)	79	
FOX-7 (recryst., < 70 μm)	63	>340
RDX	38	126

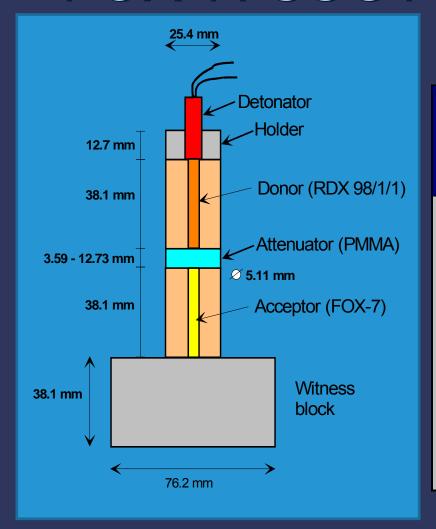


FOX-7: DSC





FOX-7: SSGT



EXPLOSIVE	DENSITY (g/cc)	Attenuator Thickness (mm)
Tetryl	1.65	8.36
HNS II	1.635	7.19
TNT	0.92*TMD	6.4
HMX	0.92*TMD	10.3
RDX	0.92*TMD	9.33
FOX-7	1.634	6.22



FOX-7

Small-scale gap test

Name	Density	Distance (50% probability point)
FOX-7	1.63 g/cm ³ (86% of TMD)	6.2 mm
TNT	1.53 g/cm ³ (92% of TMD)	6.4 mm
RDX	1.66 g/cm ³ (92% of TMD)	9.3 mm

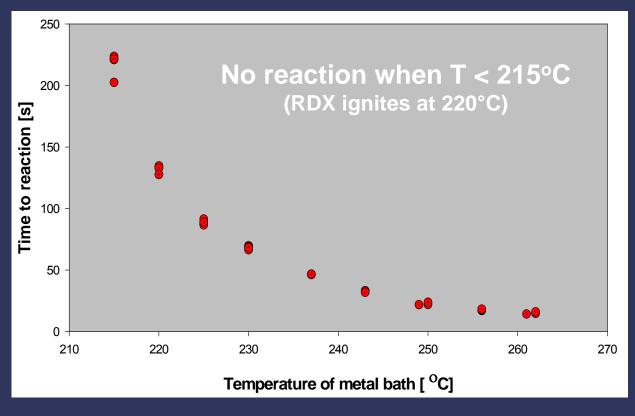
Air gap test

Name	Density	Distance (50% probability point)
TNT	1.51 g/cm ³ (91% of TMD)	34 – 35 mm
FOX-7	1.72 g/cm ³ (91% of TMD)	35 – 37.5 mm
Composition B	1.59 g/cm ³ (91% of TMD)	60 – 62.5 mm



FOX-7: Ignition Temperature (Wood's metal bath)







FOX-7: KOENEN TEST (Steel sleeve test)



Type "F" reaction at nozzle plate diameter 6 mm RDX explodes at nozzle plate diameter 8 mm



FOX-7: Compatibility by HFC

$$C_{ab} = E_{ab} - \frac{E_a - E_b}{2}$$

Incompatible: C>20 J/g/week

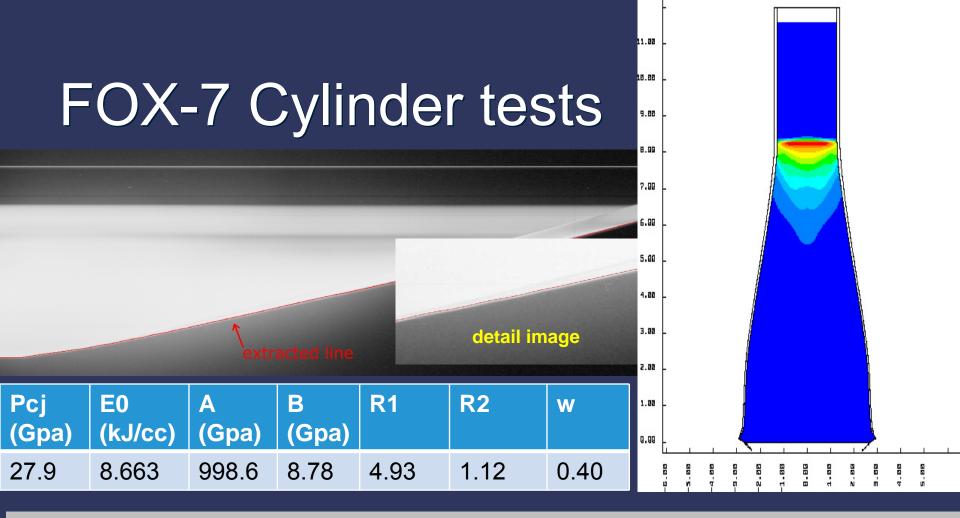
Slightly Incompatible:

10 J/g/week C<20J/g/weel

Compatible: C<10 J/g/week

Polymer	E_a (J/g/week)	C _{ab} (J/g/week)
CAB (BF900)	0.38	-0.38
Estane	0.27	-0.26
GAP (SNPE)	2.57	-0.44
HTPB (R-45 HT)	1.89	3.89
HTPB (Krasol LBH)	0.24	0.13
Viton	0.10	0.03
Isocyanate		
$H_{12}MDI$	0.70	0.41
Plasticizer		
Butyl-NENA	1.07	0.16
K-10	0.41	0.44



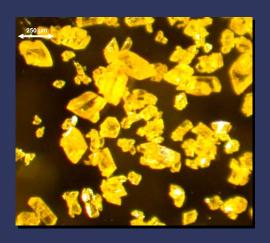


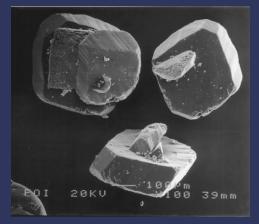
Data for FOX-7 + 1.5 w% wax, δ = 1.756 g/cc The detonation velocity was estimated to 8.335 ± 0.025 mm/ μ s; A Cheetah calculation, BKWC, gave a velocity of 8.266 mm/ μ s, which is in good agreement with the experimental value.



FOX-7

- Candidate for ingridients in
 - Boosters
 - 🛶 Shape Charge warheads
 - High performance warheads
 - Rocket and gun propellants
- Particle size and particle quallity is very important for sensitivity and processing properties

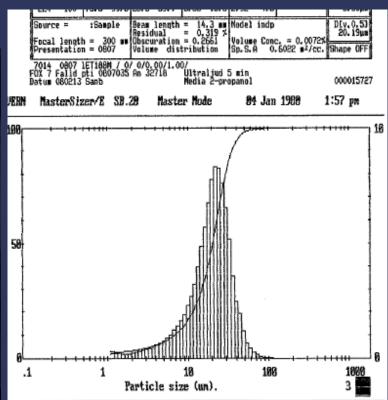








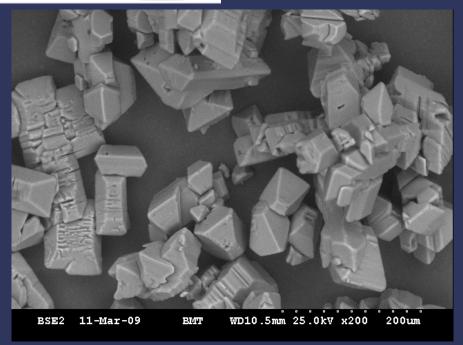


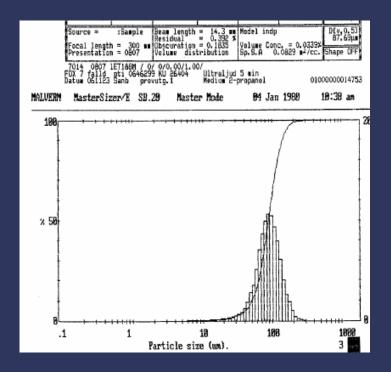


NSF 110 (20 – 40 μ m) is the smallest particle size available which also gives a relatively low bulk density, < 0.6 g/cm³ according to Hall measurements. Below, a SEM-photo with a1000 times magnification is shown together with a particle size distribution measured by Malvern is shown.





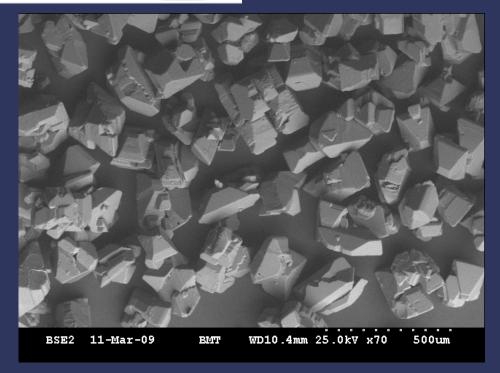


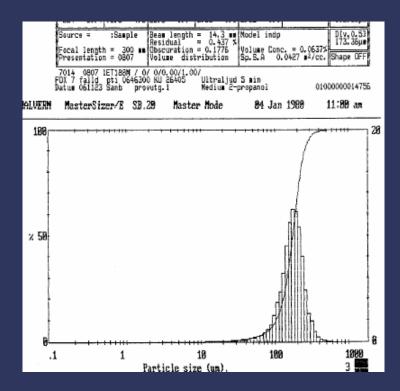


NSF 120 (50 - 100 μ m) gives a bulk density of approximately 0.7 g/cm³ according to Hall. The picture shows a 200 times magnification of the particles and a particle size distribution measured by Malvern.





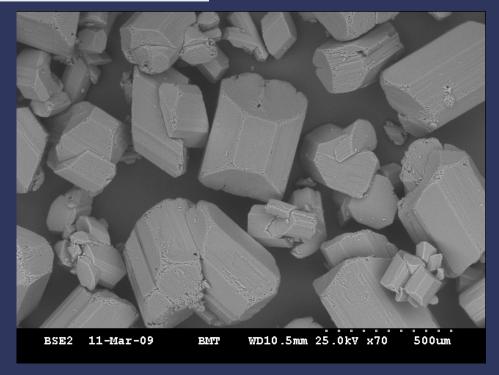


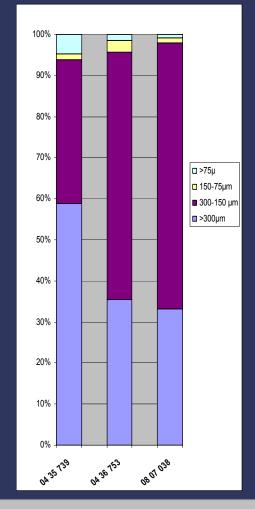


NSF 130 (100 - 200 μ m) gives a bulk density of approximately 0.85 g/cm³. The SEM photo is a 70 times magnification and the particle size distribution is a Malvern measurement.









NSF 140 (250 - 350 μ m) is the largest particle size available at present. This quality has a bulk density of approximately 0.95 according to Hall. The SEM photograph is 70 times magnification and sieving results for a couple of batches are shown a long side.





Scaling up of FOX-7

- Eurenco Bofors AB has produced nerly 1000 kg (7 kg batches, 1 to 3per day) of FOX-7 in its own pilot plant
- Molar yield 80 % for nitration step
- Very small particle size has caused problems to wash the filter cake. A separate washing step has been introduced to obtain pure product
- HPLC-purity is more than 99 % for washed product



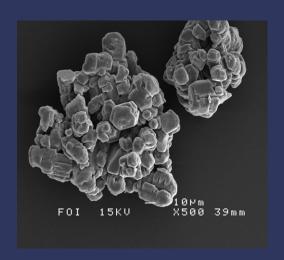


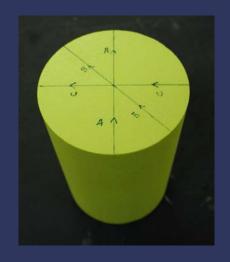
Insensitive Formulations and Applications



Pressed Explosives

- Pressed FOX-7/wax (97.8/2.2 wt%)
- Investigated as an explosive for use in shape charge applications









Pressed Explosives

- Jet straightness
- Jet velocity
- Fragmentation time
- → FOX-7 > Comp B









- ✓ Penetration (ARMOX 300S)
- → FOX-7 230 mm (2.9 cal)
- → Comp B 265 mm (3.3 cal)



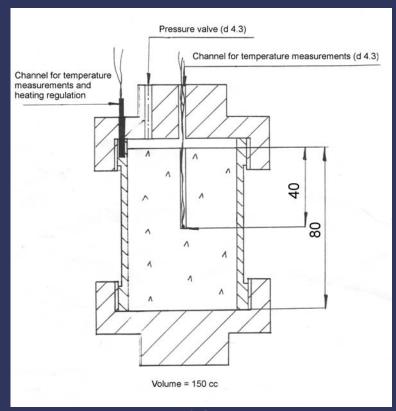
FOF-2

→ FOX7	(255-350mm)	50 wt%
--------	-------------	--------

Thermally stable at 65°C (14 days)



Small-scale slow cook-off



100-400°C Heating rate: 3.3°C/hour







Small-scale slow cook-off - Results



RDX/TNT 60/40

T_{cook-off} 207°C (Type I reaction)



FOF-2

T_{cook-off} 220°C (Type V reaction)



A New Explosives Formulation - FOF-5

→FOX-7 (238µm)	38.1 %
→ FOX-7 (32μm)	25.4 %
→ HMX (22 μm)	16.5 %
>Energetic binder	20%
•••••PolyGlyN	7.2 %
•••••GAP	7.2 %
 Butyl-NENA	3.6 %
[™] H ₁₂ MDI (Desmodur-W)	2.0 %
•••}DBTDL	



Slow Heating (Slow Cook-Off)





First test (inert fuze)

⇒ Type V response (fire)

Second test (HNS II-based fuze) ⇒ Type IV response (deflagration)

Composition B

⇒ Type I response (detonation)



Fast Heating/Fuel Fire (Fast Cook-Off)



Blast pressure (max 160 Pa) and no significant heat radiation

⇒ Type IV response (fire)

Debris (fuze) recovered at > 24 meters from test stand

⇒ Type IV response (deflagration)

Composition B ⇒ Type I response (detonation)



Bullet Impact



Debris (fuze) recovered less than 15 meters from test stand

⇒ Type V response (fire)

Composition B ⇒ Type I response (detonation)



A Potential IM Explosive?

 FOF-5 is a cast-cured explosive based on FOX-7 and HMX with the same performance (calc.) as Composition B (RDX/TNT 60/40).



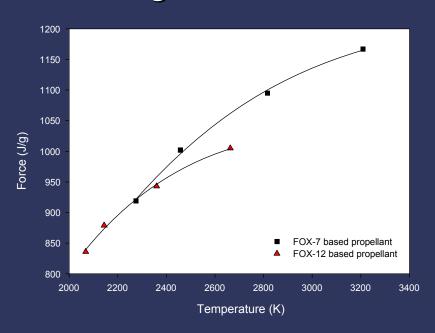
 Initial IM testing of ammunition containing FOF-5 - results:

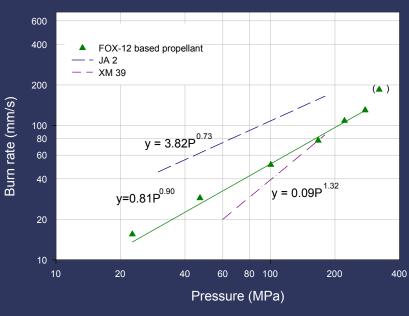
	Slow Cook-Off	Fast Cook-Off	Bullet Impact
FOF-5	Fire (1st test)	Deflagration	Fire
(Batch No. 1)	Fire/Defl (2nd test)		
Composition B	Detonation	Detonation	Detonation



Composite propellants

- FOX-12/RDX and FOX-7/HMX based compositions
- 🔫 Energetic binder







Low Sensitivity Explosives HE



Conclusions

- FOX-7 is very insensitive.
- FOX-7 makes it possible to produces low sensitivity charges with high performance, as exemplified by the shaped charge and 40mm small caliber examples.
- The availability of more and better characterized particle sizes will enable an easier development of new low sensitivity, high performance applications.
- FOX-7 is available in large quantities







Novel Plasticizer for IM Compliant Solid Propellants

Ana Racoveanu, David A. Skyler and Benjamin K. Leipzig Physical Sciences Inc.

Scott K. Dawley Aerojet

Approved for Public Release 09-MDA-4414 (17 APR 09)

Disclaimer:

"The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official Department of Defense position, policy, or decision."

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Physical Sciences Inc.



VG09-052-1

- 36 year-old company of 180 talented scientists, and engineers
- We work in headquarters in Andover, MA, with five satellite locations in the United States
- Acoustics
- Electro-magnetics
- Fluid physics
- Life sciences
- Chemical sciences
- Energetic Materials
- Optical sciences
- Plasma physics
- Space physics



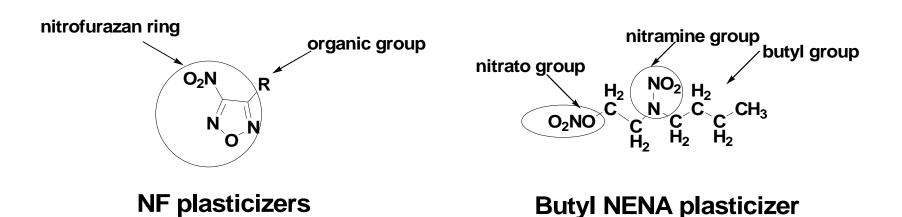


Nitrofurazan Plasticizers (NF)



VG09-052-2

 Nitrofurazan family offers promise as high energy, good thermal behavior, high density and low sensitivity plasticizers



- NF core: heterocyclic ring with high thermal stability, good density
- Organic Group R: capability to functionalize the nitrofurazanic core
- R group variation may generate various categories of NF plasticizers



Background: NF1



VG09-052-3

- PSI synthesized and characterized NF1 from low cost precursors (30% yield)
- Aerojet performed the energetic and thermal properties testing: promising plasticizer with good energy and good density

	Density Gm/cc	Decomposition Temperature, °C	∆Hf, Kcal/mol
NF1 theor	1.620	180	69.5
NF1 exp.	1.467	180	58.8
Butyl NENA	1.211	165	-45.55
TMETN	1.488	158	-105.8
BTTN	1.520	154	-92.6



Background: NF1 Cont'd



VG09-052-4

NF1 properties

- Low viscosity fluid
- Moderate volatility

Measurements show it is insensitive

- Category "Green" [normal]

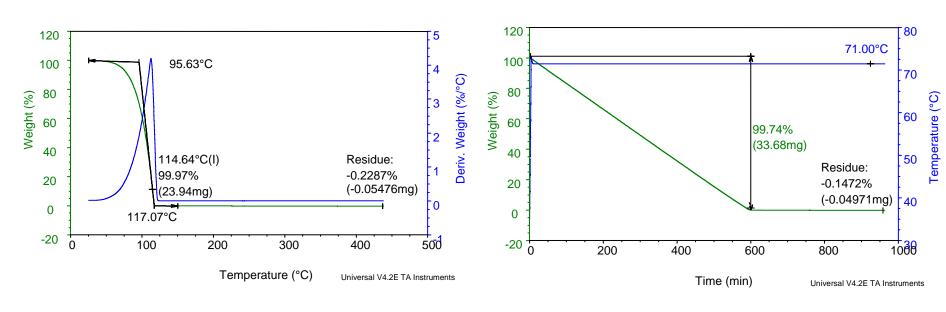
Hazard	NF1	RDX
Impact, kg-cm	145	49
Friction, psi @ drop angle, º	1800 @ 90°	1200@90°
ESD, J @ 5kv	6.0	0.38



Background: NF1 Cont'd



VG09-052-5



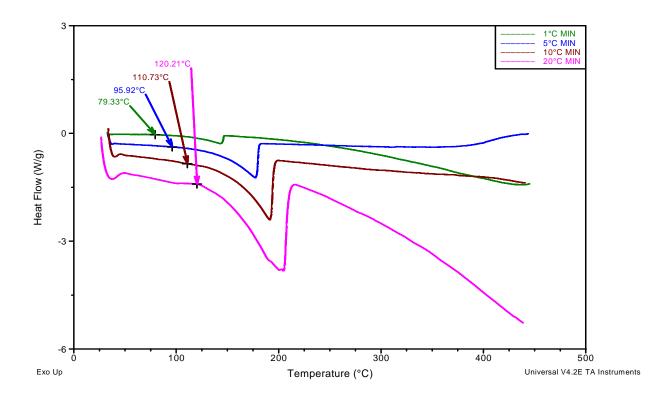
Onset of weight loss in TGA occurs at a low temperature

Isothermal TGA shows material evaporates after 10 hr at 70°C

Chemical modification to NF1 was required to eliminate volatility



VG09-052-6



In Differential Scanning Calorimetry (DSC) only endotherms noted due to vaporization – no exotherms

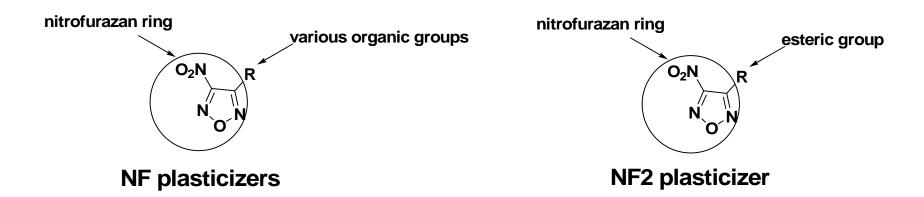


Novel Nitrofurazan Plasticizer: NF2



VG09-052-7

- Variation of the R group generated various NF classes of nitrofurazanic plasticizers
- R = esteric group: Esteric NF Plasticizers Candidates
- NF2 showed good energy, good density and acceptable volatility





VG09-052-8

	Density G/cm ³	Decomposition Temperature, °C	∆Hf, Kcal/mol
NF2 exp.	1.264	176.4	-62
NF1 exp.	1.467	180	58.8
Butyl NENA	1.211	165	-45.55
TMETN	1.488	158	-105.8
BTTN	1.520	154	-92.6

NF2 has good sensitivity and good thermal properties

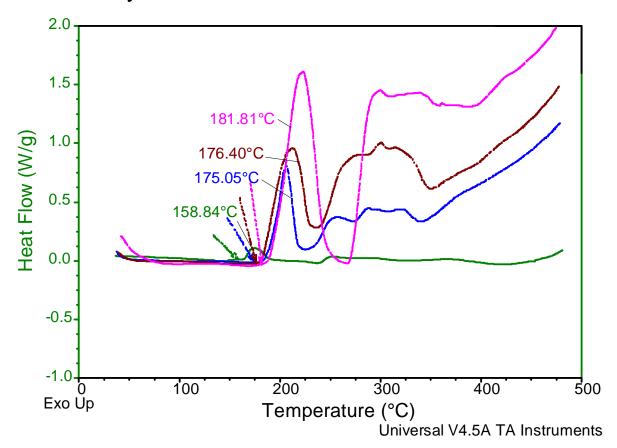
Hazard	NF2	RDX
Impact, kg-cm	300	49
Friction, psi @ drop angle, º	1800 @ 90°	1200@90°
ESD, J @ 5kv	6.0	0.38





VG09-052-9

DSC Overlay: 1 °C/min., 5 °C/min., 10 °C/min., 20 °C/min.



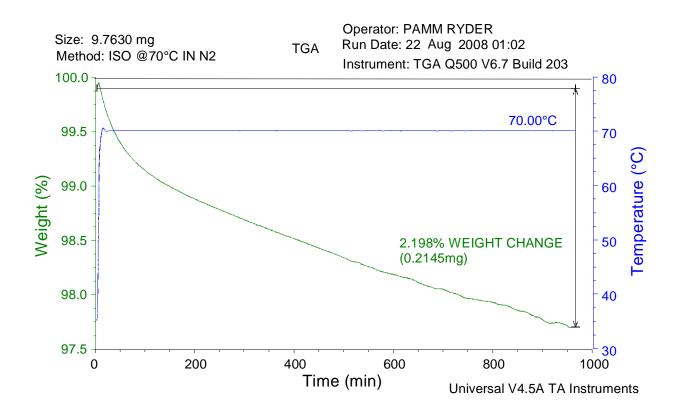
In Differential Scanning Calorimetry (DSC) only exotherms were noted: low volatility of NF2





VG09-052-10

TGA ISO @ 70°C FOR 16 HRS



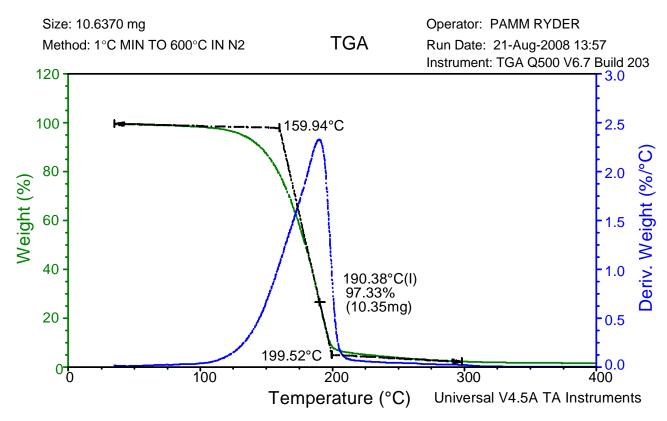
NF2 has low volatility: 2% loss in weight at 70 °C for 16 hrs





VG09-052-11

Thermal Gravimetric Analysis 1°C MIN



Onset in the weight loss for NF2 starts above 100 °C



Conclusions



VG09-052-12

- NF2 has been successfully synthesized and characterized in a 40% overall yield
- NF2 synthesis used low cost precursors and was produced in high purity (>98%)
- NF2 Testing Results: insensitive ("green" category material)
- NF2 showed good thermal properties: it has good decomposition temperature and low volatility
- Additional work will be conducted NF2 will be incorporated in propellant samples (work in progress at Aerojet)



Acknowledgments



VG09-052-13

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VG09-052-14

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

QUALIFY AN ALTERNATE POLYISOBUTYLENE (PIB) BINDER FOR COMPOSITION C-4





QUALIFY AN ALTERNATE POLYISOBUTYLENE (PIB) BINDER FOR COMPOSITION C-4

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Energetics Producibility and Manufacturing Technology Division
RDECOM-ARDEC, Picatinny Arsenal, NJ

2009 Insensitive Munitions & Energetic Materials
Technology Symposium
Tucson, AZ
11-14 May 2009





- Acknowledgement
- Background
- Qualification Status
 - Specification
 - Sensitivity
 - Performance
 - Compatibility
 - Extrudability
- Summary





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- PM Close Combat Systems
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- RDECOM-ARDEC
 - Mr. Greg Tremarco
 - Mr. Paul Vinh
 - Mr. Sanjeev Singh
 - Ms. Maria Bukowska
 - Mr. Mike Mauriello
 - Mr. Drew Smith
- Milan Army Ammunition Plant
 - Mr. Dave Duncan
- Crane Army Ammunition Activity
 - Mr. Stacy Vanhoy



BACKGROUND



- Composition C-4, Class 3 is produced by BAE Systems at Holston Army Ammunition Plant
 - 88.9% RDX Explosive
 - 9.9% Plastic Binder
 - 1.2% DMDNB Taggant
- Composition C-4 is mainly used for demolition purposes
 - M112 Demolition Charge
 - M183 Demo Kit
 - MICLIC
 - M18A1 Claymore Mine







BACKGROUND



- Approximately 23% Polyisobutylene (PIB) in the plastic binder
- ExxonMobil sole qualified PIB producer
 - Vistanex MML-120
 - ExxonMobil ceased all PIB production
- BASF markets its own PIB, called Oppanol
- PM-CCS initiated effort to qualify BASF Oppanol PIB
- Market survey confirmed BASF sole supplier of CONUS PIB similar to qualified Vistanex
 - BASF Oppanol PIB grades B-100, B-150, and B-200



BASF Oppanol P



BACKGROUND



- BASF PIB grades were tested for specification compliance and further evaluated in Composition C-4 lab-scale batches
- Oppanol B-150 and B-200 were down-selected for scale-up production and qualification testing based on:
 - Rheological characterization
 - B-100 does not meet 2 specification requirements
 - B-150 and B-200 meets all but the intrinsic viscosity specification requirement (higher intrinsic viscosity)
- Polyisobutylene

- Intrinsic viscosity affects flow, i.e. higher value the more viscous
- Higher molecular weight PIB to coat RDX particles







QUALIFICATION STATUS Specification Compliance



 PIB grades used in scale-up C-4 production analyzed for specification compliance, MIL-P-13298



	MIL-P-13298 PolylsoButylene		BASF Oppanol B-150		BASF Oppanol B-200			Vistanex MML-120		
	Spec	ification	Lot #:	Lot #:	Lot #:	Lot #:	Lot #:	Lot #:	(control)	
Specification	Min.	Max.	0804	0805	0805 0806		0807 0808		(33	
Intrinsic Viscosity	3.15	3.72	4.621*	5.012*	3.996*	6.237*	4.763*	5.236*	3.62	
lodine No.		1.32	0.9123	0.5963	0.7261	1.0120	0.8763	0.6973	0.89	
Chlorine, %		0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	
Acidity, % AS HCL		0.01	0.002	0.003	0.001	0.001	0.003	0.004	0.000	
Insoluble Matter		0.20	0.03	0.09	0.08	0.02	0.04	0.07	< 0.20	
Color	= s</td <td>tandard</td> <td>< std</td>	tandard	< std	< std	< std	< std	< std	< std	< std	



* Failed Specification



QUALIFICATION STATUS Specification Compliance



 All 6 scale-up Composition C-4 batches (4,000 lb/batch) produced with Oppanol PIBs are MIL-C-45010A specification compliant

	MIL-C-45010A Comp C-4, Class 3		Com	Comp C-4 with B-150			Comp C-4 with B-200			
			Batch #: R7577	Batch #: R7578	Batch #: R7579	Batch #: R7580	Batch #: R7581	Batch #: R7582		
Specification	Min.	Max.	(PIB Lot#: 0805)	(PIB Lot#: 0804)	(PIB Lot#: 0806)	(PIB Lot#: 0807)	(PIB Lot#: 0808)	(PIB Lot#: 0809)		
% RDX	89.8	91.2	90.6	90.5	90.6	90.2	90.2	90.2		
% Binder	8.8	10.2	9.4	9.5	9.4	9.8	9.8	9.8		
% DMDNB	1.00	1.50	1.14	1.30	1.40	1.38	1.18	1.16		
% Moisture		0.25	0.03	0.02	0.01	0.07	0.04	0.05		
USSS 40		0	0	0	0	0	0	0		
USSS 60		5	0	0	0	0	0	0		
Plasticity	0.018		0.176	0.131	0.142	0.140	0.167	0.117		





QUALIFICATION STATUS Sensitivity and Performance



 Sensitivity and performance of Composition C-4 with Oppanol B-150 PIB comparable to the control

	C403-R7576 (Control)	C403-R7577 (#1, B-150)	C403-R7578 (#2, B-150)	C403-R7579 (#3, B-150)
ERL, Type 12 Impact Test	87.4 ± 1.4 cm	75.7 ± 2.0 cm	60.7 ± 0.7 cm	60.7 ± 0.9 cm
BOE Impact Test	1/10 (4" Height)	0/10 (4" Height)	0/10 (4" Height)	1/10 (4" Height)
ABL Friction Sensitivity Test, (1800 psi)	0/20 Trials	0/20 Trials	0/20 Trials	0/20 Trials
Electrostatic Sensitivity (ESD), (0.25J)	0/20 Trials	0/20 Trials	0/20 Trials	0/20 Trials
Large Scale Gap Test (LSGT)	1.645"		1.925"	1.805"
Ignition & Unconfined Burning, (Seconds)	Trial 1: 93 Trial 2: 106 Trial 3: 92	Trial 1: 94 Trial 2: 89 Trial 3: 110	Trial 1: 108 Trial 2: 102 Trial 3: 117	Trial 1: 133 Trial 2: 106 Trial 3: 137
Detonation Velocity & Plate Dent	V = 7.86 km/s Dent = 0.118"		V = 7.96 km/s Dent = 0.118"	V = 7.90 km/s Dent = 0.113"





QUALIFICATION STATUS Sensitivity and Performance



 Sensitivity and performance of Composition C-4 with Oppanol B-200 PIB comparable to the control

	C403-R7576 (Control)	C403-R7580 (#1, B-200)	C403-R7581 (#2, B-200)	C403-R7582 (#3, B-200)
ERL, Type 12 Impact Test	87.4 ± 1.4 cm	94.4 ± 1.4 cm	48.3 ± 1.1 cm	55.2 ± 1.9 cm
BOE Impact Test	1/10 (4" Height)	0/10 (4" Height)	0/10 (4" Height)	0/10 (4" Height)
ABL Friction Sensitivity Test, (1800 psi)	0/20 Trials	0/20 Trials	0/20 Trials	0/20 Trials
Electrostatic Sensitivity (ESD), (0.25J)	0/20 Trials 0/20 Trials 0/20		0/20 Trials	0/20 Trials
Large Scale Gap Test (LSGT)	1.645"	1.875"	1.700"	
Ignition & Unconfined Burning, (Seconds)	Trial 1: 93 Trial 2: 106 Trial 3: 92	Trial 1: 120 Trial 2: 115 Trial 3: 93	Trial 1: 111 Trial 2: 133 Trial 3: 136	Trial 1: 114 Trial 2: 117 Trial 3: 137
Detonation Velocity & Plate Dent	V = 7.86 km/s Dent = 0.118"	V = 7.74 km/s Dent = 0.108"	V = 7.98 km/s Dent = 0.117"	





QUALIFICATION STATUS Sensitivity, Performance, & Aging



- Composition C-4 batches made with Oppanol B-150 and B-200 PIB, tested for impact, friction, electrostatic, shock sensitivity, and performance properties are comparable to the control batch made with Vistanex PIB
- No significant problems or anomalies during testing evaluation
- Accelerated aging of test batches with sensitivity and performance properties to be compared to the control batch
 - Impact, friction, and rheology testing every 1, 2, 4, 6, 8 months
 - LSGT and detonation velocity at 0 & 8 month
 - Second month completed to date







QUALIFICATION STATUS Compatibility



- Composition C-4 produced with Oppanol B-150 and B-200 PIB passes compatibility testing with Mylar bag (Mylar bag used in wrapping C-4 block in M112 demolition charge)
 - Differential Scanning Calorimetry (DSC) used to measure enthalpy changes of material for compatibility



	Test Sample	DSC Exotherm, Peak Temperature	Criteria	Result
Control	C-4 (B-150 PIB)	234.54°C		
Control	C-4 (B-200 PIB)	236.08°C		
Test #1	C-4 (B-150) & Mylar bag-a	232.87°C	Within 4°C of control	Pass
Test #2	C-4 (B-150) & Mylar bag-b	234.72°C	Within 4°C of control	Pass
Test #1	C-4 (B-200) & Mylar bag-a	236.98°C	Within 4°C of control	Pass
Test #2	C-4 (B-200) & Mylar bag-b	234.88°C	Within 4°C of control	Pass





QUALIFICATION STATUS Extrudability



 Composition C-4 made with Oppanol B-150 and B-200 PIB successfully extruded into M112 demolition charges at Milan Army Ammunition Plant (American Ordnance) and at Crane Army Ammunition Activity without any significant problems

- Extrudability, i.e. process control parameters, of the 6 batches/lots (2,000 lbs each) made with Oppanol comparable to the control batch/lot
- All lots pass LAT at Milan AAP (Lot Acceptance):
 - Three lots with Oppanol B-150
 - Three lots with Oppanol B-200
 - One control lot with Vistanex MML-120
- All C-4 batches/lots, made with Oppanol PIB, extruded into M112 demolition charges pass extrusion evaluation





SUMMARY



- Vistanex MML-120, sole qualified polyisobutylene (PIB) for use in Composition C-4, is no longer produced by ExxonMobil and Vistanex tradename was sold to BASF
- BASF produces a similar product with various grades, called Oppanol (no other CONUS producers of similar PIB as determined by market survey)
- Three BASF Oppanol PIB grades (B-100, B-150, & B-200) tested and B-150 & B-200 selected for scale-up evaluation qualification
- Composition C-4 batches produced with Oppanol B-150 & B-200 were tested for impact, friction, electrostatic, shock sensitivity, performance properties, and extrudability which are all comparable to the control batch made with qualified Vistanex PIB
- Final qualification of Oppanol B-150 & B-200 to be completed in Fall 2009 pending completion of aging evaluation







IM Solutions For Projectiles Crimped to Cartridges for Artillery Application - Phase II, Transition from Cartridge Case Venting to Insensitive Propellant

Carl J. Campagnuolo, Christine M. Michienzi, Edward G. Tersine, Christine D. Knott, William J. Andrews

NDIA IM/EM Symposium May 11-14, 2009







Background

- The PGU 44/B cartridge for the AC 130 aircraft consists of a cartridge case and a projectile that are crimped together
- Both components are IM sensitive

Munition	Platform	Propellant	Explosive	FCO	SCO	BI	FI	SD	SCJ
PGU 44/B	105-mm	M1	CompP	-		_			1
PGU 44/B	Howitzer	IVI I	CompB	•	'	1	1	•	'

- Separate effort to replace HE (Comp B → PBXN-109)
- This effort only for propelling charge (M67) and propellant (M1)
 - Vent holes were placed in the cartridge case
 - at the base
 - on the forward end
 - Insensitive propellant





Venting Effort





Venting Holes for SCO & FCO

(Past work – Phase I; Type V reactions)



Cartridge Case with 30 3/8" diameter holes on forward end



Cartridge case with 6 3/4" diameter holes at base





SCO Test Results - Type V



Cartridge case with holes at forward end



Cartridge case with holes at base





FCO with Vent Holes – Type V



Cartridge case with holes at forward end, parts were found near the pit



Cartridge case with holes at base seen on the pit table, after the bonfire test





IM Explosive – PBXN-109



After firing – cartridge case urethane plastic plugs



Comparison of lethality on concrete target



NAVSEA WARFARE CENTERS

Fuze Cap and Cartridge Case Venting Plugs

- E = Eutectic of bismuth, lead, copper and tin
 - starts to melt at 200° F; fully melted at 240° F
- F = Formion
 - becomes soft at ~ 250° F and started to melt when T > 300° F
- K = Polyamide Polymer
 - starts to melt at 160° F; fully melted at 200°
 F.
 - improved plug later developed starts to melt at 200° F; fully melted at 250° F
- Formion fuze cap
 - starts to melt at ~275° F then wax (the explosive stimulant) begins to exit through the nose cap.



Fuze cap, E, F and K Plugs



SCO, with PBXN-109 Inert Propelling Charge with Plugs



Charred remains of container



Formion plugs consumed

Type V reaction; event took place at 425°F



FCO of Cartridge with M67 Propelling Charge, Inert Explosive, Plugs – E, F and K



Test Items – Post Test



Base with E plugs



FCO, AUR Formion Plugs and Fuze Cap





Formion plugs – carbonized instead of melting



Projectile with nose plug consumed





Propellant Effort





Propellant

- Leverage propellant development programs for Navy's 5-inch and 155-mm gun systems
- NILE propellant
 - Improved IM over Navy's single base BS-NACO propellant
 - Similar properties to M1 used in 105-mm M67 round



Propellant	Impetus (J/g)	Covolume (cm³/kg)	Gamma	Flame Temp (K)
M1	942	0.1076	1.271	2537
NILE	895	0.1190	1.279	2175







Slow cook-off – Type V reaction – pass!!





Current Mk 67 Mod
3 charge (BSNACO) gives
explosive reaction
(Type III)





WARFARE CENTERS

IM Testing of NILE Propellant

Fragment Impact – Type IV reaction



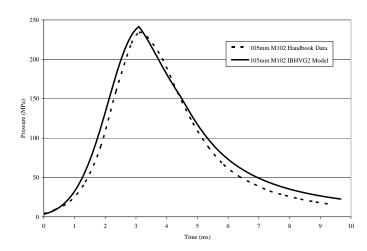
Current Mk 67 Mod
3 charge (BSNACO) gives
explosive reaction
(Type III)





Interior Ballistics Model

- Developed using IBHVG2 (lumped parameter 0-D code)
- Validated with data for current M1 propellant
 - Minor time offset is due to the lack of primer ignition delay in the IB model
 - Velocity 490 m/sec (model), 492 m/sec (LAT data)



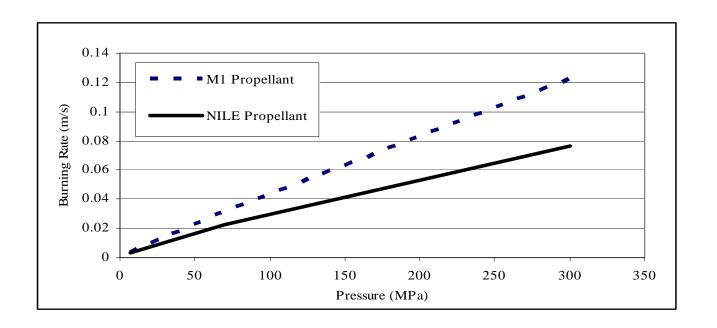
 IB model use to determine NILE grain geometry that would match M1 ballistic performance





Interior Ballistics Model

- Burning rates of NILE compared to M1
 - Lower burning rate, ok smaller grains usually = better IM







Interior Ballistics Model

Grain geometry of NILE determined

Grain	Perf #	Length (in)	Outer Diam (in)	Perf Diam (in)	Web (in)	ρ (g/cm ³)	Recommened Charge Weight(lb _m)
Optimized	1	0.055	0.06	0.029	0.016	1.616	3.17
Actual	1	0.058	0.062	0.025	0.019	1.588	3.22

- Actual grains manufactured slightly different size not unusual
 - Swelling during extrusion
 - Contraction during drying







Test Configuration

- Dugway Proving Ground 105mm M102 Howitzer
- Data collection
 - Projectile muzzle velocity (dual Weibel radar)
 - Maximum breech pressure (M-11 copper crusher gauges)
- Spotter rounds fired first
 - Warm gun
 - Calibrate data collection systems
- Reduced charge NILE rounds
- Full charge NILE rounds





Test Configuration



85% NILE3





Test Configuration

Test Matrix										
General					Propelling Charge			Data Collection		
Test #	Test Date	Propelling Charge Designation	QE (mil)	Projectile Type	Fuze Type	Propellant Type	CW (lbm)	Cond Temp (°F)	Weibel Radar Track	M-11 Gages
1	9/11	Spotter-1	10	105H	M564	M1	2.82	AMB	Y	0
2	9/11	Spotter-2	20	105H	M564	M1	2.82	AMB	Y	0
3	9/11	Spotter-3	25	105H	M557	M1	2.82	AMB	Y	0
4	9/11	Spotter-4	25	105H	M557	M1	2.82	AMB	Y	0
5	9/11	M67-1	25	105H	M557	M1	2.82	AMB	Y	2
6	9/11	NILE2	25	105H	M557	NILE	2.27	AMB	Y	2
7	10/30	Spotter-5	27.5	105H	M564	M1	2.82	AMB	Y	0
8	10/30	Spotter-6	27.5	105H	M564	M1	2.82	AMB	Y	0
9	10/30	M67-2	27.5	105H	M564	NILE	2.82	AMB	Y	3
10	10/30	NILE3	27.5	105H	FMU153	NILE	2.75	AMB	Y	3
11	10/30	NILE1	27.5	105H	FMU153	NILE	3.24	AMB	Y	3
12	10/30	M67-3	35	105H	M564	M1	2.82	AMB	Y	3
13	10/30	NILE4	35	105H	M564	NILE	3.39	AMB	Y	3
14	10/30	NILE5	35	105H	M564	NILE	3.49	AMB	Y	3
15	10/30	NILE6	250	105H	FMU153	NILE	3.54	AMB	Y	3
16	10/30	NILE7	250	105H	FMU153	NILE	3.49	AMB	Y	3





Test Data

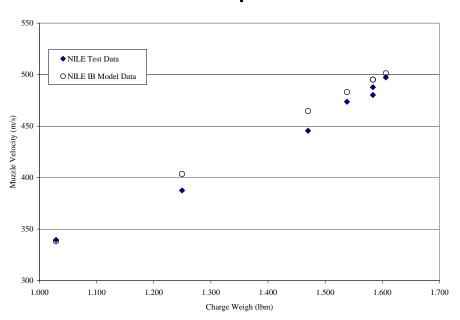
	Ger	neral		Pre	dicted	Actual		
Test Number	Test Date	Propelling Charge Designation	CW (kg)	Muzzle Velocity (m/s)	Max. Breech Pressure (psi)	MV _{avg} (m/s)	Avg. Max. Breech Pressure (psi)	
1	9/11/2008	Spotter-1	1.281	448	35089	489	ND	
2	9/11/2008	Spotter-2	1.281	448	35089	486	ND	
3	9/11/2008	Spotter-3	1.281	448	35089	489	ND	
4	9/11/2008	Spotter-4	1.281	448	35089	490	ND	
5	9/11/2008	M67-0	1.281	448	35089	492	36750	
6	9/11/2008	NILE1	1.029	338	14876	340	15000	
**	**	**	**	**	**	**	**	
7	10/30/2008	Spotter-5	1.281	448	35089	492	ND	
8	10/30/2008	Spotter-6	1.281	448	35089	489	ND	
9	10/30/2008	M67-1	1.281	448	35089	489	37100	
10	10/30/2008	NILE3	1.250	404	21569	388	21025	
11	10/30/2008	NILE1	1.470	465	30424	445	28700	
12	10/30/2008	M67-2	1.281	448	35089	489	35250	
13	10/30/2008	NILE4	1.538	483	33747	474	33850	
14	10/30/2008	NILE5	1.583	495	36131	480	35125	
15	10/30/2008	NILE6	1.606	501	37413	497	45300	
16	10/30/2008	NILE7	1.583	495	36131	488	42100	

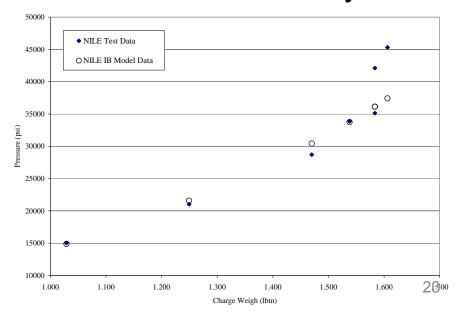




Test Data

- Good agreement with IB model predictions
- High pressures due to non-ideal ignition pressure waves
 - especially at higher pressures, but no corresponding increase in projectile velocity
 - Used standard igniter not optimized for NILE
 - Anticipated will be addressed in further study









Conclusions and Future Work

- F plugs have been excluded; future designs will have E or K plugs
- First test of NILE in 105-mm howitzer was a success
- Further optimization of the propellant (granulation) necessary
- Optimization of primer necessary
 - Primer propellant less sensitive than black powder
 - Increase tube length eliminate non-optimal ignition/pressure waves
- IM testing of propelling charge to demonstrate improvement





2009 INSENSITIVE MUNITIONS & ENERGETIC MATERIALS TECHNOLOGY SYMPOSIUM 11-14 May 2009

Loews Ventana Canyon Resort, Tucson AZ

Insensitive Munitions (IM) Improvement MK22 Mod 4 Rocket Motor (#7963)

Matthew Sanford

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Robert Hutcheson

Code E312F, Bldg 302-114

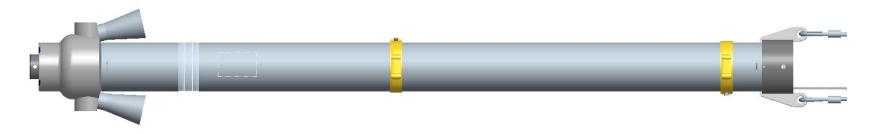
Randolph Johnson

Code E313D, Bldg 301



Outline

- Background
- Program Objectives
- Design Approach
- Vents
- Rocket Initiator Thermally Actuated (RITA)
- Concept Testing
- Future Efforts





Mine Clearance System Description

- Mine-clearing device used to clear a path for tanks, vehicles and personnel through minefields or other obstacles
- System clears a path 350 ft long by 46 ft wide
- Deployment Platforms
 - Mk 1 Mod 0:
 - 3 line charges deployed from inside an AAV, uses the Mk 154 Hydraulic Launcher
 - Mk 2 Mod 0:
 - 1 line charge deployed from the ABV or M353 Trailer towed behind any armored/tracked vehicle, uses the Mk155 Hydraulic Launcher
- Uses Rocket Motor for towing the line charge over obstacles or minefields for breaching, training or test applications
- Effective against single-impulse, pressure-type, nonblast hardened anti-tank mines and mechanically actuated anti-personnel mines







Objectives: RM Program

SYSTEM	FCO	sco	ВІ	FI	SD	SCJ
Current Performance MK 22 MOD 4 ¹	(IV)	≡	V	III	Pass	Unknown
Expected IM Improved Performance EX 22 MOD 5	(V-IV)	(V-IV)	V	(V-IV)	Pass	Unknown

- Design, Build, and Prove Out an Improved IM MK 22 Rocket Motor for Procurement in FY 09/10
 - Primary:
 - Slow Cook-Off (SCO) Performance Improvement
 - Goal: Type V Reaction (Burning)
 - No Performance Change
 - No Change in Deployment of Linear Demolition Charge
 - Secondary:
 - Minimization of Cost
 - Rapid Retrofit of Current Inventory



Slow Cook-Off Criteria

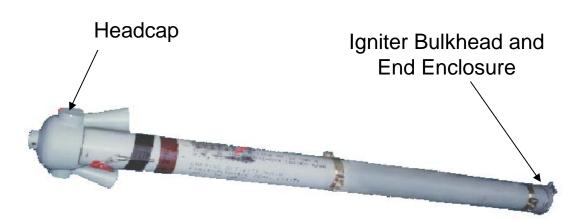
- MIL-STD-2105 Type V (Burning Reaction)
- Test Configuration
 - In the Shipping Container based on THA, SSHA, and IMO inputs
- Munitions Behavior
 - Energetic Materials: Combustion
 - Case: Benign split, smooth gas release/end separation
- Effects
 - Projection of Materials < 50 ft



Rocket Motor Improvements

- Seeking IM improvement in MK 22 RM
 - Performance across temperatures eliminates composite propellants from consideration
 - Application mandates an inexpensive, rugged design
 - Eliminates composite case, making strip laminate case undesirable
 - Venting possible solution
 - Data suggests venting alone will not cure the problem

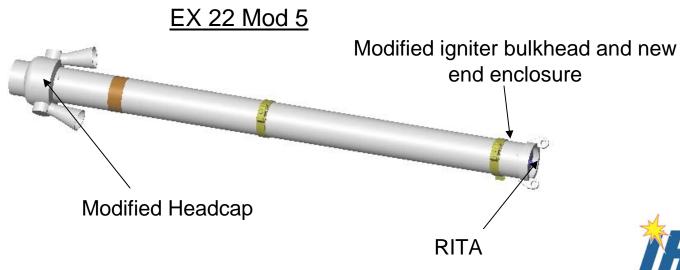
MK 22 Mod 4





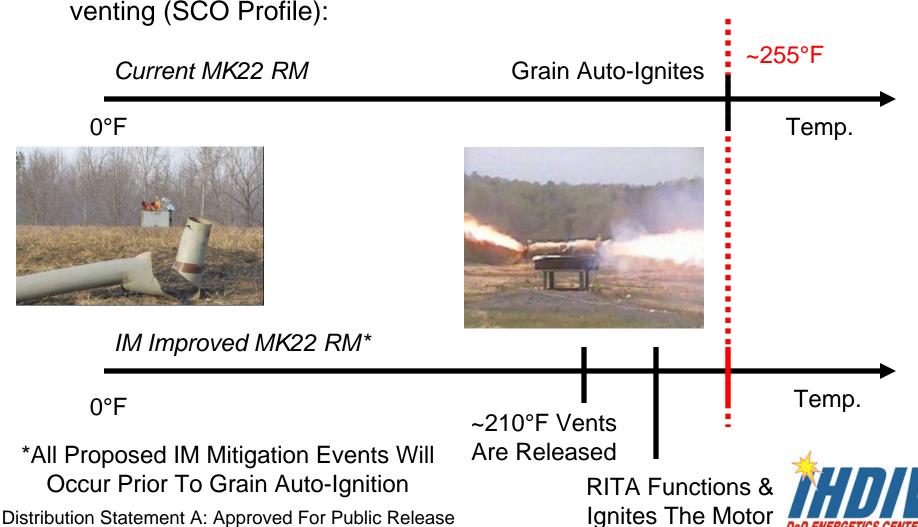
Rocket Motor Improvements

- Proposed Solution:
 - Fully vent both ends using a thermally activated shape memory alloy (NiTiNOL) release mechanisms
 - Modify headcap
 - Modify igniter bulkhead
 - New end enclosure
 - Ignite surface of propellant prior to auto-ignition using an Active Mitigation Device (AMD)
 - Rocket Initiator Thermally Actuated (RITA)



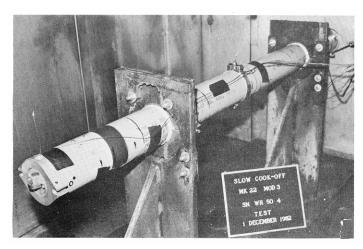
RM IM Improvement Approach

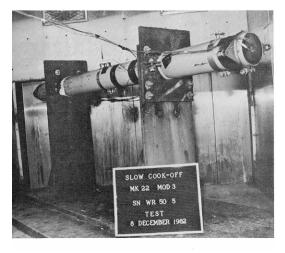
Design approach temperature timeline to allow safe, controlled venting (SCO Profile):



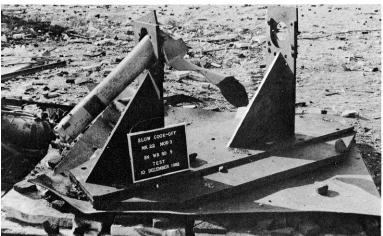
Excellence for the Warfighter

Background: Mk 22 Mod 3 Slow Cook-Off History



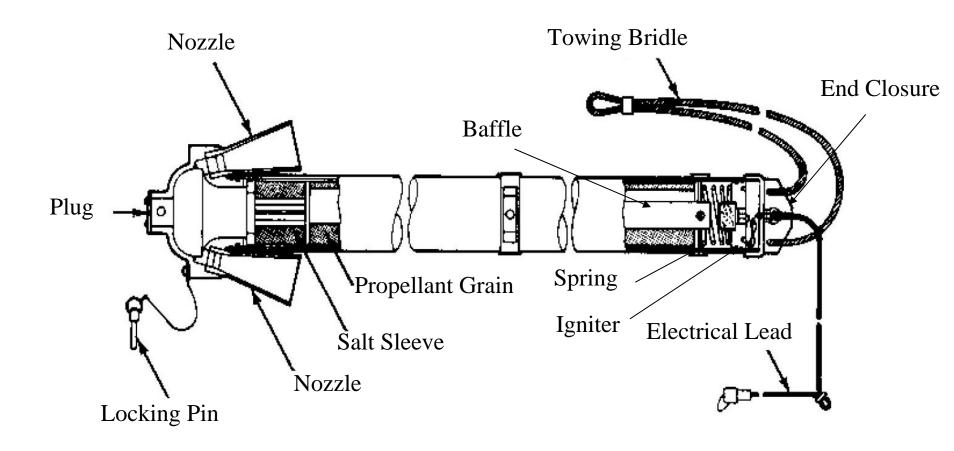








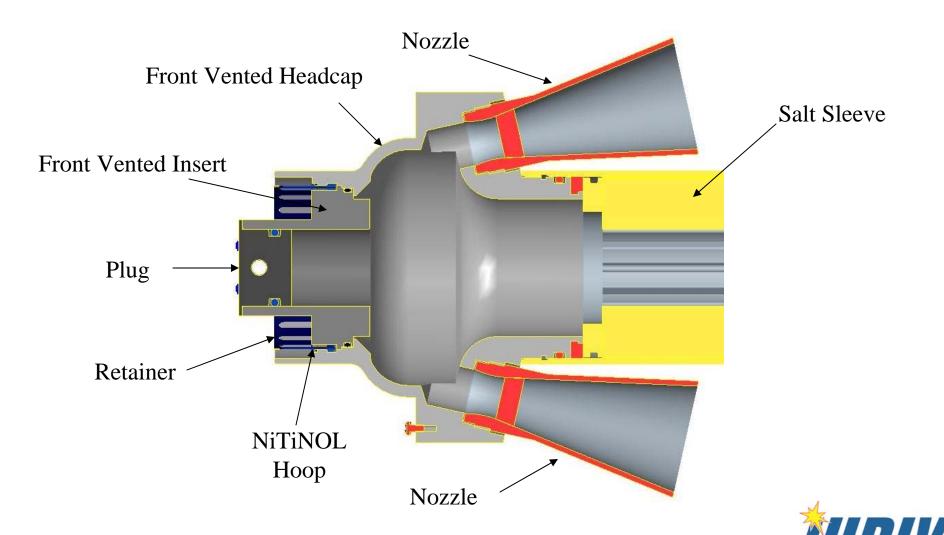
MK22 Mod 4 Rocket Motor Current Production Configuration



N-5 Double Base Propellant Autoignition Temperature ~255°F

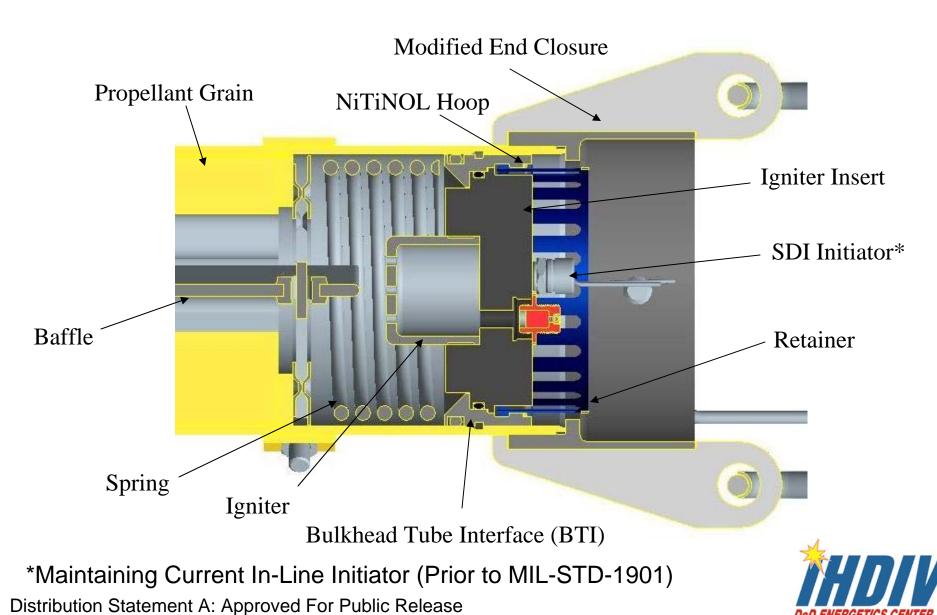


EX 22 Mod 5 - Fwd Vent



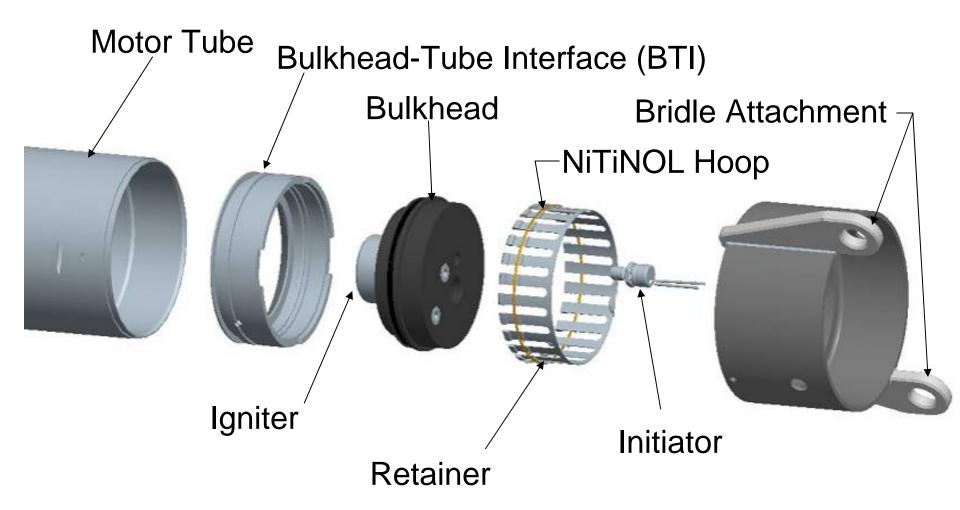
Excellence for the Warfighter

EX 22 Mod 5 – Aft Vent



Excellence for the Warfighter

Thermally Venting Bulkhead

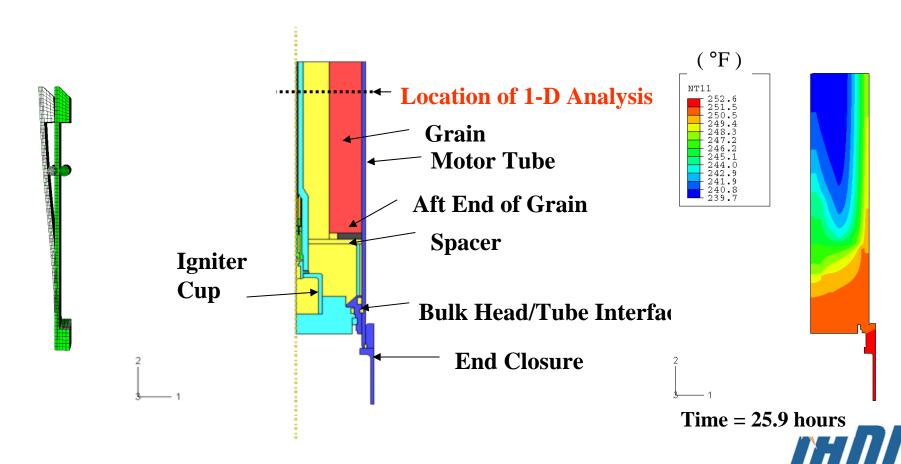


*RITA Not Pictured



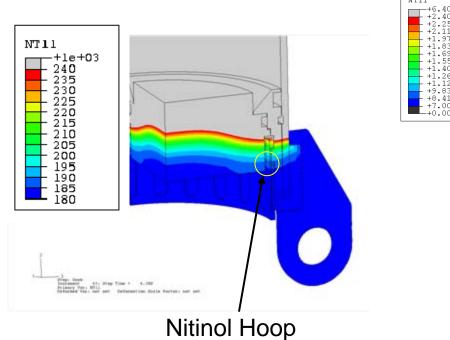
Vent Thermal & Structural Analysis

- Thermal Analysis
 - Slow Cook-Off Analysis Predicts Venting Mechanism Function & Verified Heating Profile of Motor

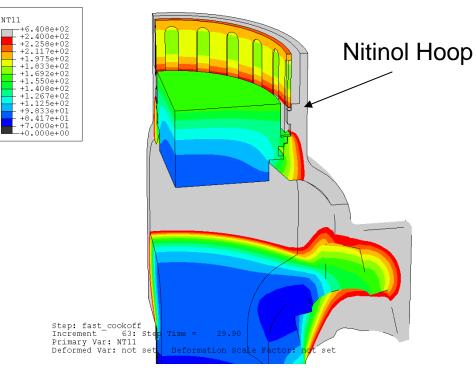


Vent Thermal & Structural Analysis

- Thermal Analysis
 - Hot Motor Firing Predicts Venting Mechanism Retained
 - Fast Cook-Off Analysis Predicts Venting Mechanism Function



Hot Motor Firing (Aft End)

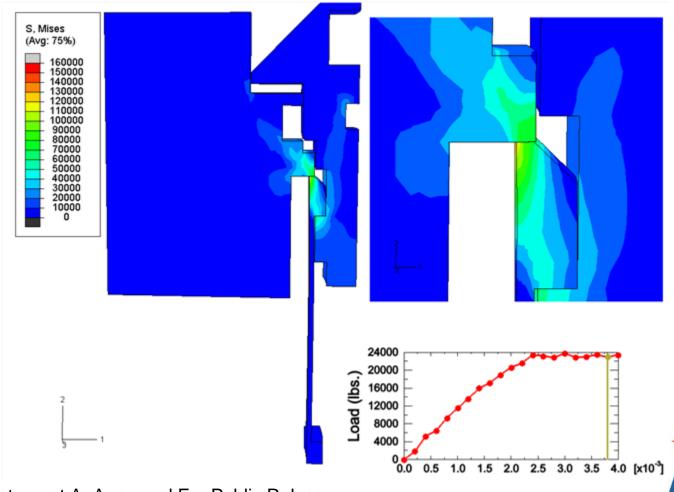


Fast Cook-off (Headcap)



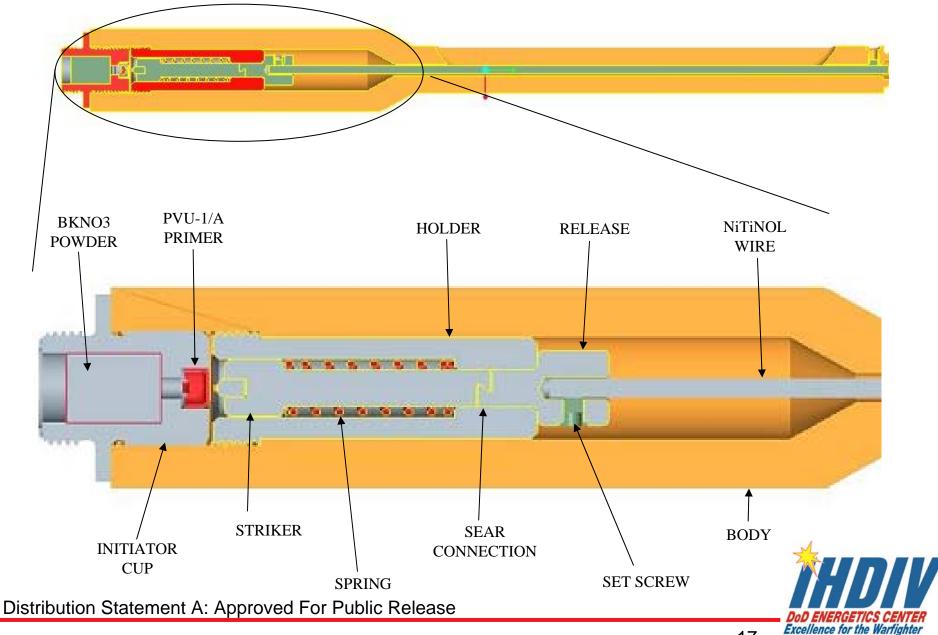
Vent Thermal & Structural Analysis

- Structural Analysis
 - Firing Loads Retainer Expected To Hold At Maximum Firing Loads

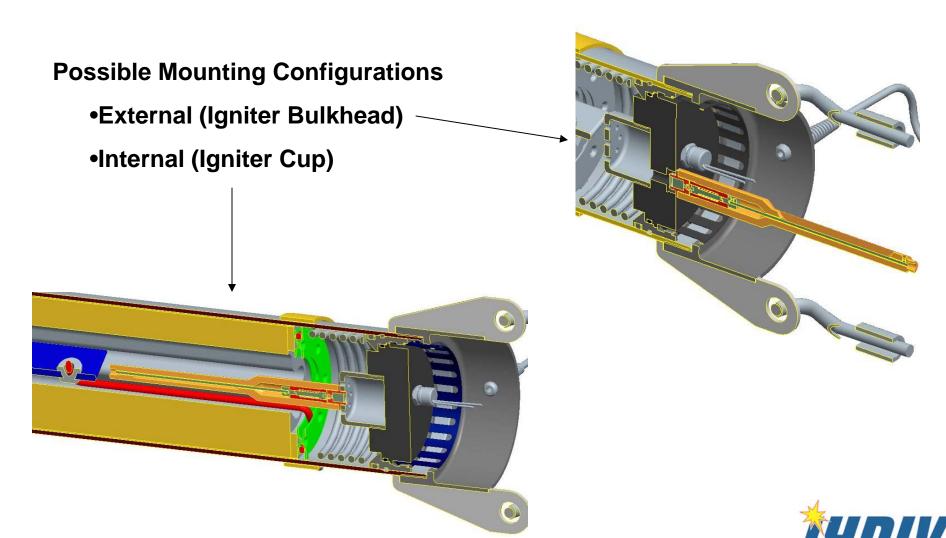


Excellence for the Warfighter

RITA Design (Preliminary Configuration)



RITA Design (Preliminary Configuration)



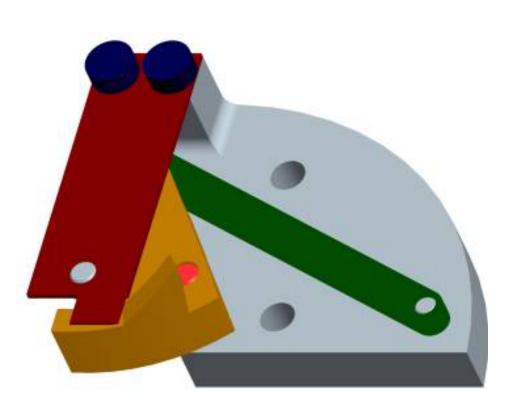
RITA Design (Preliminary Configuration)

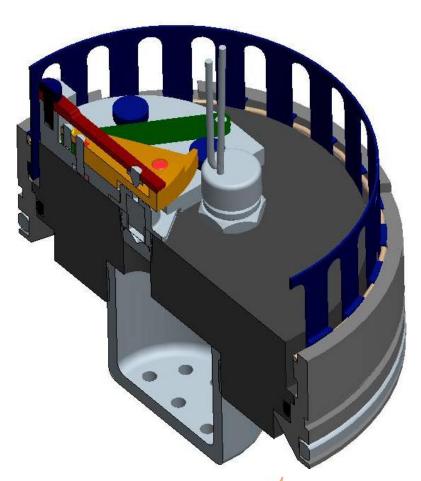
Design Deficiencies:

- Striker/Primer/Initiator Charge In-Line
- Possible Inadvertent Actuation Due to Shock
- Mounting Issues:
 - Internal
 - Structural Integrity
 - Flow Impact (Baffle)
 - Temperature Exposure
 - External
 - Length Limitations
 - Possible Use As A Handle



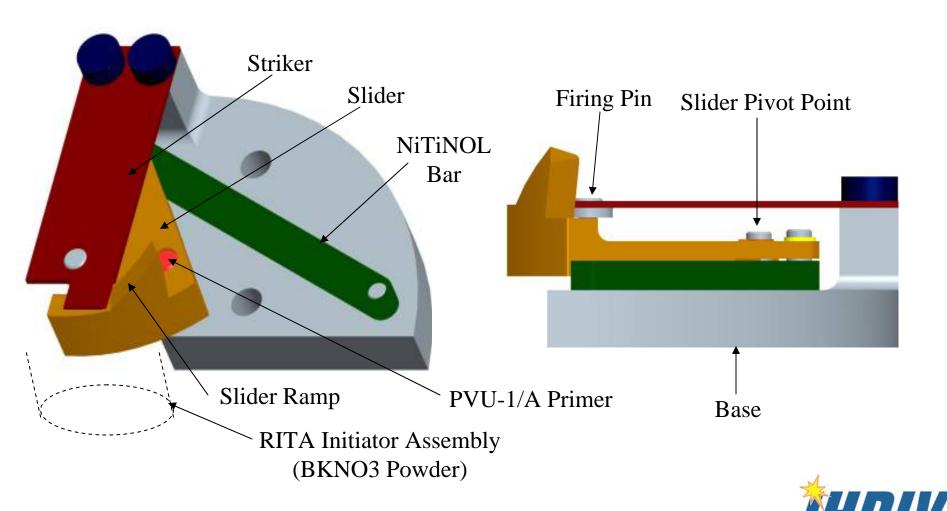
Revised Low-Profile RITA Design:







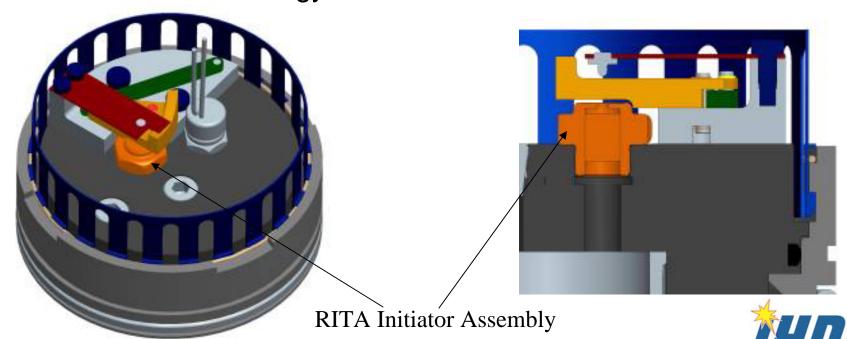
RITA Design (Revised Design) Safe Position



Excellence for the Warfighter

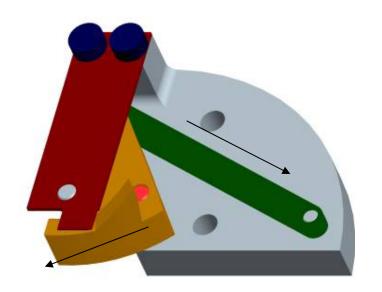
Actuation Process:

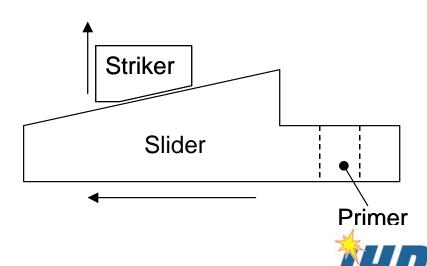
- RITA In Safe Position
 - Primer Out of Line With Initiator Charge
 - NiTiNOL Bar Is A Structural Member (Device Lock)
 - No Stored Energy



Actuation Process Cont'd:

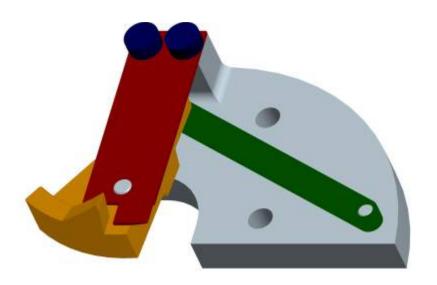
- 2. RM (RITA) Exposed To Cook-off Environment (SCO or FCO)
 - NiTiNOL Bar Begins To Contract
 - Slider Begins To Pivot
 - Striker Begins Moving Along Slider Ramp

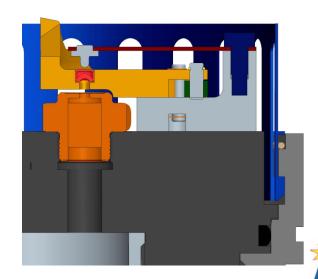




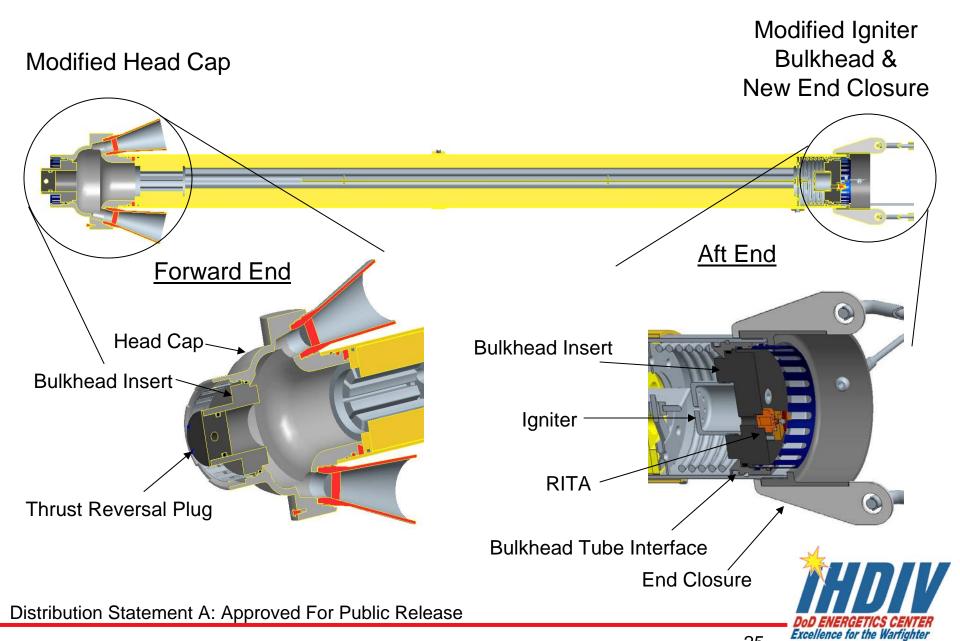
Actuation Process Cont'd:

- RITA Fully Actuates (Armed Position)
 - NiTiNOL Bar Completes Contraction
 - Slider Completes Pivot Motion
 - Striker Reaches the Apex of Slider Ramp And Releases
 - Firing Pin Impacts Primer
 - Begins Ignition of Initiator Charge / Igniter / RM





EX 22 Mod 5 with RITA



Rocket Motor Explosive Information

EX 22 Mod 5 Energetic Materials			
Component	Explosive	Weight	
Propellant	N-5, Double Based	42.00 lbs.	
Electrical Initiator	Bridgewire Composition 500486 (ZrKClO4)	65 mg	
	Initiator (BKNO3)	220 mg	
Igniter	Igniter Charge (MTV)	48 g	
RITA	RITA Primer PVU-1/A (Lead Styphnate)		
	BKNO3	220 mg	

Only New Energetic Materials



Concept Testing

- Slab Motor Tests
 - Determined Propellant Could be Safely Ignited At Elevated Temperatures
- High Temperature Vented Test
 - Proved Active Mitigation Device Required
- High Temperature Ignition Test
 - High Temperature Ignition Viable
- Previous RITA Design
 Performance Tests
 - Verified Primer & Initiator Charge
 Sufficient In Igniting RM



High Temperature Ignition Test (Double Venting)



RITA Future Efforts

RITA Functionality Test Series:

- NiTiNOL Performance Validation
 - % Reduction Verification
 - Tensile & Compression Strength
 - Force Generated When Activated
- 2. Initiator Performance Characterization
 - Firing Pin to Primer Performance*
 - Primer / Initiator Gap Analysis
 - Primer to BKNO3 Transfer*
 - BKNO3 to Igniter Transfer*
 - Primer / Initiator Offset (Progressive Arming)
- 3. Full-up RITA Performance Demonstration
 - Full-up RITA In SCO environment
- 4. EX22 Mod 5 SCO Demonstration
 - Venting & RITA
- RM / RITA Qualification



^{*}Building Off of Previous RITA Testing

Acknowledgements

- Intrinsic Devices Inc. for their Support in Developing Requirements for the NiTiNOL
- ATR for their Support in Configuration Review and Design Input
- EODTECHDIV
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 - Danny Bouch RM Production
 - Bob Johnson RITA Production
 - Diptiman Sengupta Igniter Production
 - Wesley Shaw NiTiNOL Testing
 - K C Elliot RITA Testing
 - Eric Meyer RM Static Firing Test Lead
 - Tony Kee RM Static Firing Support



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An Improved Process for the Synthesis of TATB from TETNB

2009 Insensitive Munitions and Energetic Materials Technology Symposium, Tucson, AZ

Alexander J Paraskos R&D Synthesis Chemist ATK Launch Systems Phone: 435-863-2392 alex.paraskos@atk.com

May 13, 2009





TATB is an important IM explosive material

- TATB is a key component in several important explosive formulations
 - PBXN-7, PBXW-14, PBX-9502, PBX-9503, LX-17
- TATB exhibits excellent balance of performance, thermal resistance and insensitivity to stimuli:

Compound	Sensitivity (Impact)	Deflagration Point	Density	Detonation Velocity
NTO	1200 N m	270 °C	1.91 g/cm ³	7860 m/s
TATB	50 N m	384 °C	1.93 g/cm ³	7350 m/s
TNT	15 N m	300 °C	1.65 g/cm ³	6900 m/s
RDX	7-8 N m	204 °C (mp)	1.82 g/cm ³	8750 m/s
CL-20	4 N m	195 °C (mp)	2.04 g/cm ³	> 9000 m/s

^{*} Rudolf Meyer et al, Explosives (5th edition), 2002, Wiley-VCH Publishers, Weinheim

Legacy "Benziger" Process for TATB Production



- Starting material = Trichlorobenzene (TCB)
 - TATB from TCB produces environmentally undesirable waste stream
 - TCB is toxic; TCB synthesis from chlorination of benzene
 - PRC (China) is sole source of this material; future supply uncertain and the cost of TATB production may ultimately be affected
 - Currently no qualified supplier of legacy TATB available
 - Bridgewater, Royal Ordinance, McGregor have ceased production

ATK Navy ManTech TATB Process



- Navy-funded ManTech process developed at ATK LS between 2003-2007
- Starting material = phloroglucinol (PG)
- Phloroglucinol is a biosynthetically accessible material
- Triethylorthoformate is typically used for alkylation step (form TETNB)
- Main product impurities: ammonium diaminopicrate salt (ADAP) and ethoxydiaminotrinitrobenzene (EDATB; product of incomplete ammonolysis)
- Problem: PBXN-7 formulation using ATK ManTech TATB did not perform in all necessary configurations

Reaction Impurity Formation Mechanism



A premier aerospace and defense company

- Data has shown ADAP to have a minimal effect on TATB sensitivity (safety) and small effect on thermal stability
- Elevated temperature and NH₃ pressure were reported to convert ADAP to TATB (Bellamy)

ADAP Safety Data

DSC onset/peak (°C)	303.5/306.1		
HPLC purity	99.4 %		
ABL impact	51 centimeters		
ABL friction	800 lbs @ 8 feet per		
	second		

Navy: TATB & PBXN7 Performance Differences



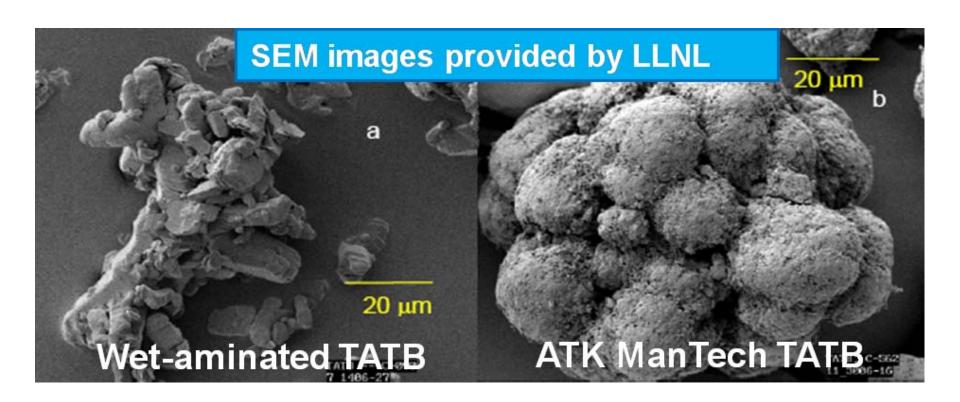
	Legacy	ATK ManTech
1st (2nd) DSC Onsets	378	353 (368)
Purity (HPLC)	99+%	97-98%
Mean Size	48	56
Bulk Density (TMD = 1.937)	1.92	1.84
PBXN-7 Density Pressed (%TMD)	99.3-99.9	94.9
FMU-152 @ Low Temp (PBXN-7)	5/5 Go's	3/5 Go's
Large Scale Gap Test (PBXN-7)	207 cards	173.5 cards

- Formulations using ManTech ATK TATB did not demonstrate acceptable performance in FMU-152 fuses at low temperature
- Purity of ATK ManTech TATB significantly lower than legacy
- Densities, pressed densities and thermal onsets lower than legacy material

TATB Particle Morphology Variation



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TATB particle morphology was used as a key screening tool

Altering the ATK Navy ManTech TATB Process



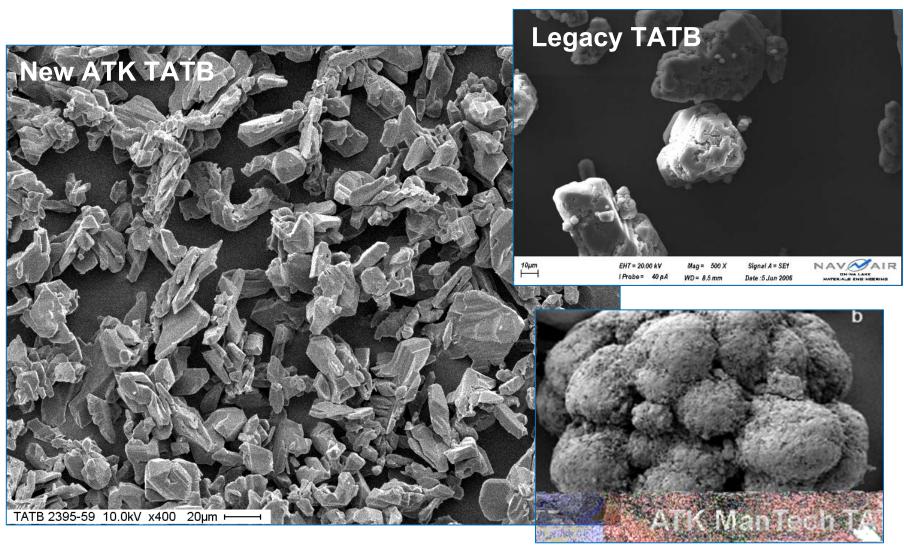
- Considered options to realize utilizable TATB by minimally altering ATK ManTech process
- TATB is difficult to modify post-process due to insolubility in solvents
- As a result, ATK LS used IR&D funding to explore numerous significant process changes to final ammonolysis step
- > 50 lab-scale synthetic experiments were run to date and > 200 supporting analyses have been made on the resulting materials
- ATK LS has seen many promising results as a result of this IR&D effort

SEM of TATB from Newly Developed Method



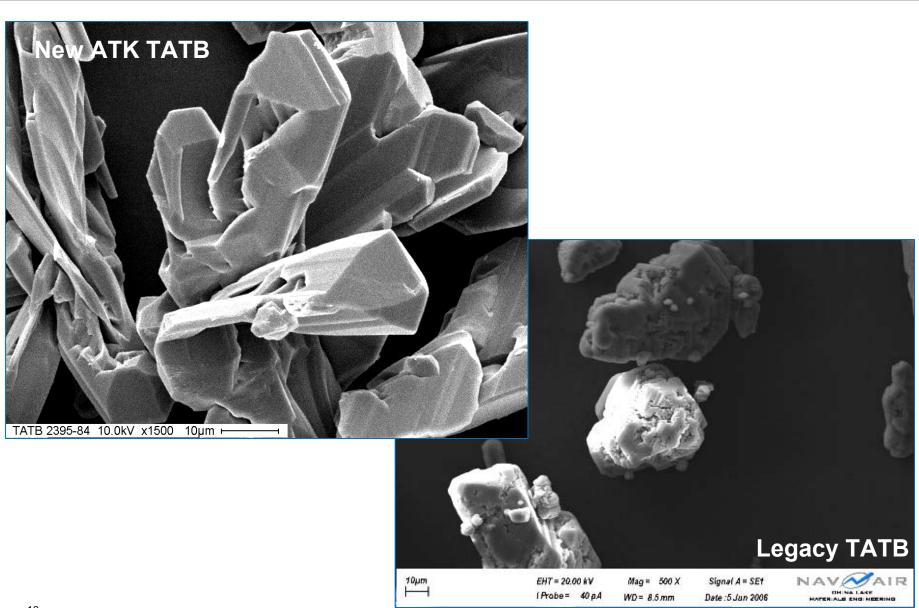
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New ATK TATB "looks" more like legacy material by SEM



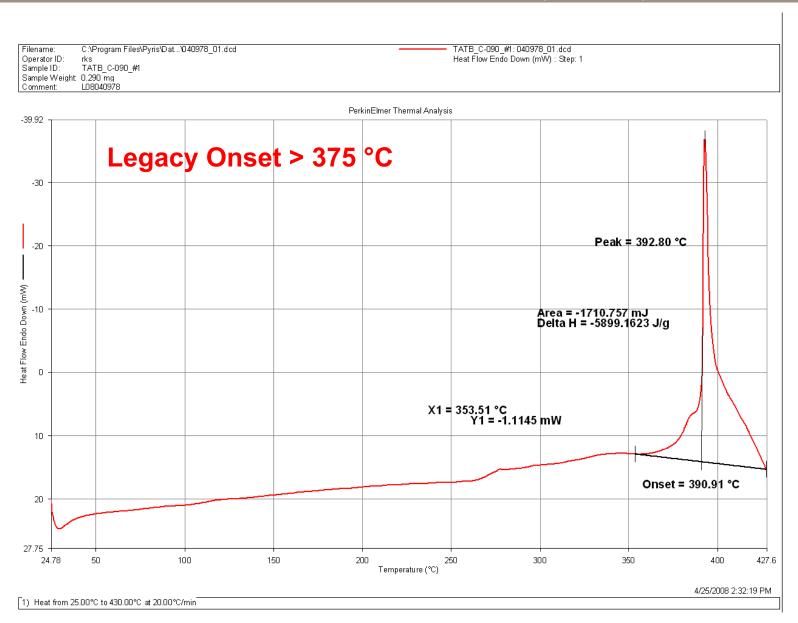
SEM of New ATK TATB & Legacy TATB





Legacy TATB DSC Data

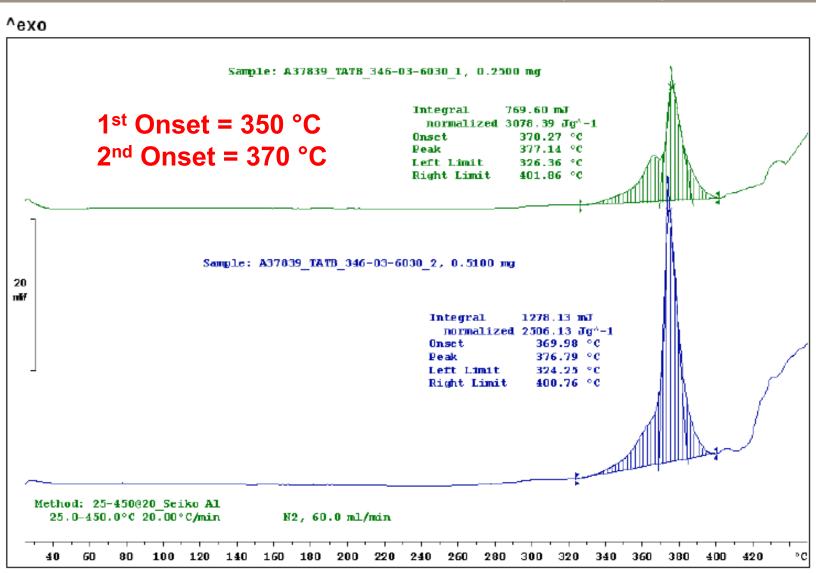




ATK ManTech Process TATB: DSC Data



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Lab: Thiokol Thermal Lab

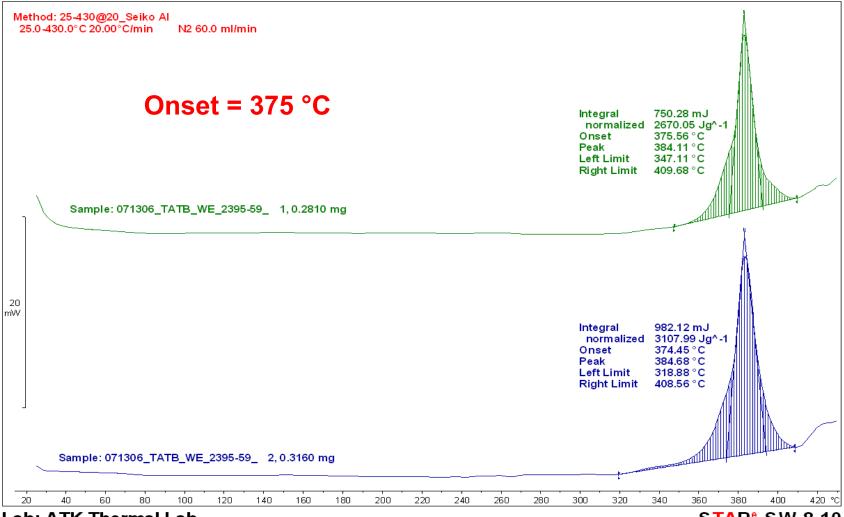
METTLER TOLEDO STAR[®] System

New ATK Process TATB: DSC Data



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Lab: ATK Thermal Lab

STAR® SW 8.10

Properties of the Newly Developed ATK TATB



	% TATB (HPLC)	ADAP	EDATB	50%Size (µm)	1 st DSC Onset (°C)	Density (gas pyc)	C,H,N (27.92, 2.34, 32.55)
New ATK 1	99.5%	0.2%	0.3%	22.53	369.8		28.20, 1.89, 32.07
New ATK 2	99.3%	0.3%	0.4%	25.75	374.5	1.90-1.91	28.21, 1.92, 32.00
New ATK 3	99.5%	0.5%	0.0%	n/a	378.0		28.14, 2.02, 32.04
New ATK 4	99.7%	0.3%	0.0%	n/a	380		28.11, 1.95, 32.03
Mantech ATK	97.6%	1.8%	0.6%	54.3	368.9	1.83-1.84	29.02, 2.04, 31.44
Legacy C-090	100%	0%	0%	70.4	> 378	1.91-1.92	27.92, 2.34, 32.55

- DSC onset temperature may improve/become more consistent with refinements to process conditions
- Bulk density is much improved; comparable to legacy material

Conclusions



- New processing conditions for the conversion of TETNB to TATB have been developed
- New conditions yield product that is much more comparable to legacy materials than previous ATK process
- Purity/decomposition temperature improved over ManTech ATK process; not quite as good as legacy but process improvements continue
- Density of new product is much improved; comparable to legacy material
- New ATK TATB appears much more crystalline, "looks like" legacy material by SEM
- 25 gram sample has been sent to China Lake for further evaluation
- 25 gram samples have been prepared for shipment to LANL and LLNL
- ATK's goal is to establish a viable process for making TATB that can be used by all potential users/consumers (DOD and DOE)

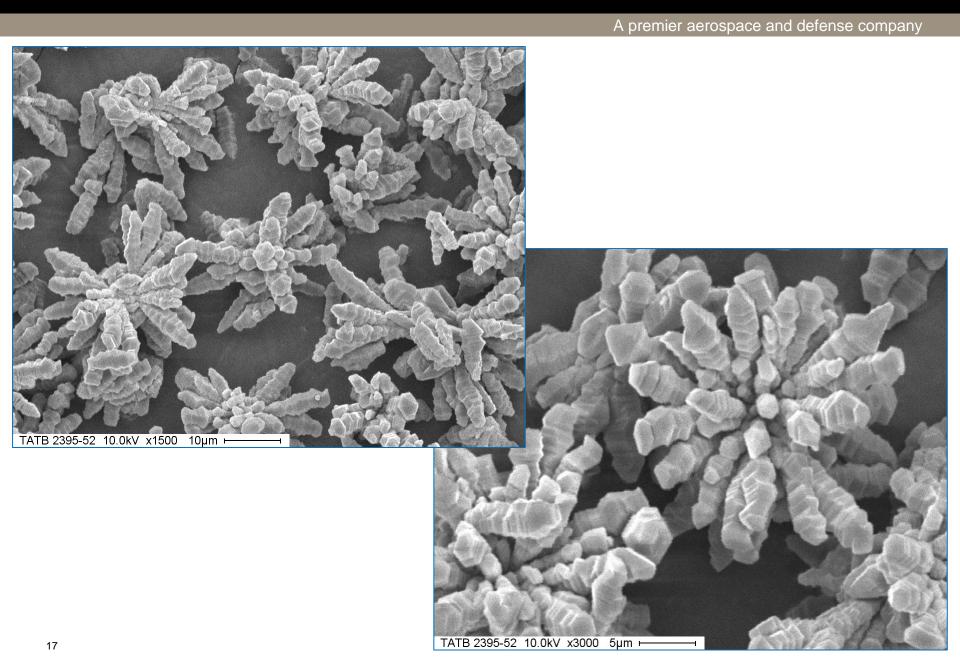
Acknowledgements



- Navy ManTech office
- Chuck Painter
- Tim Mahoney
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- Becky Olinger
- Others

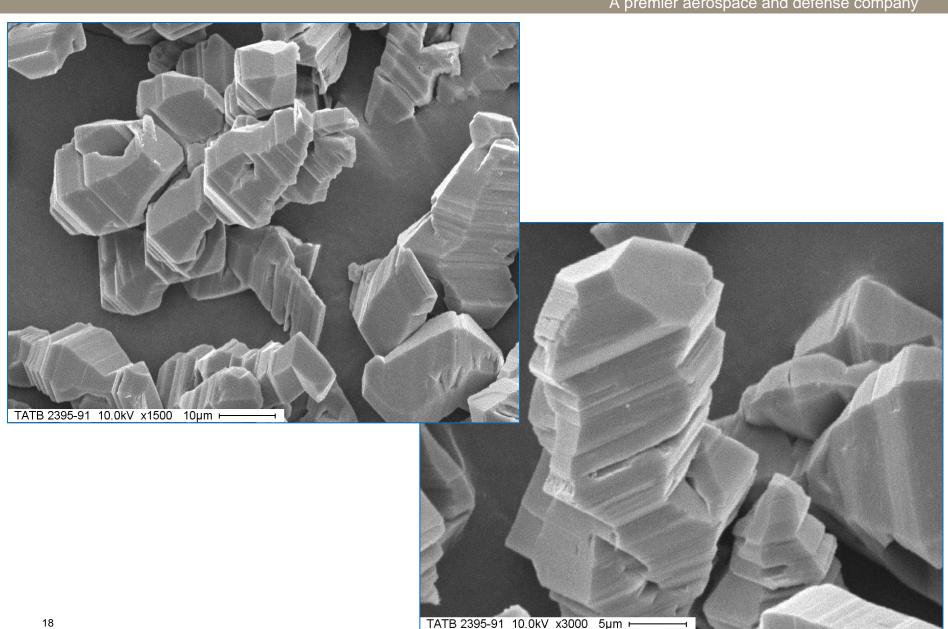
SEM from Other Explored TATB Conditions





SEM from Other Explored TATB Conditions







TECHNION – IIT



Department of Mechanical Engineering

Modeling and Testing of Ceramic Armor Tile Survivability to Fragment Attack

Presented by: Moran Shpitzer

Supervisors: Prof. Daniel Rittel

Dr. Tamar Yarom



TECHNION - IIT



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<u>Outline</u>

- Research objectives
- Experimental setup and results
- Simulation modeling
- Discussion
- Summary & Conclusions



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Research Objectives

- Modeling a ceramic (Al₂o₃) armor as an IM shield against fragment attack.
- Comparing simulations data to the corresponding tests results.



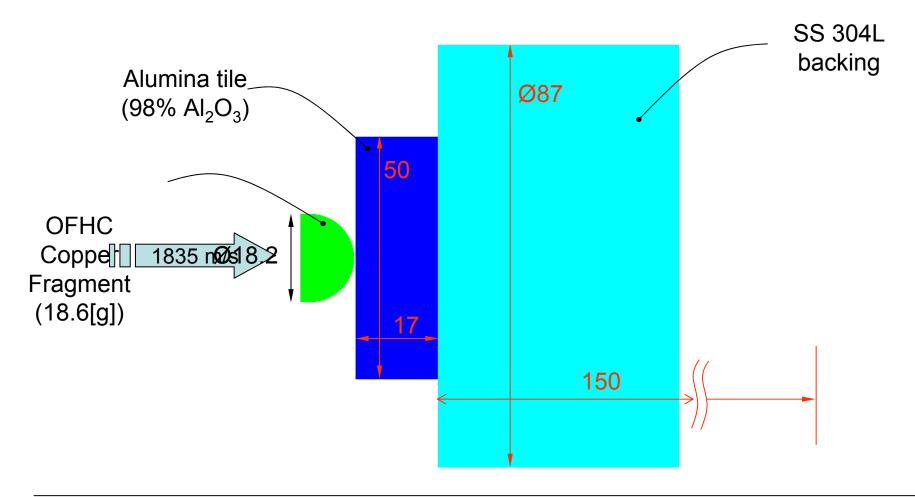
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Test Setup





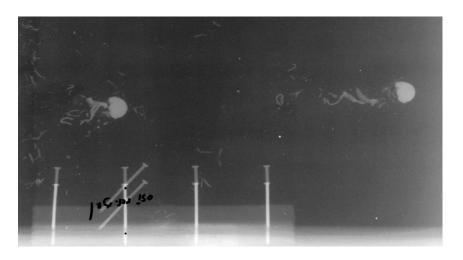


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Fragment formation

- Fragment is formed from the initiation of an EFP charge.
- An EFP charge is an explosive charge, consists of a metal casing and a 18.6 [gr] copper liner (acc. to STANAG 4496).
- After the initiation, the copper liner transforms into a hemispheric shaped fragment.
- Fragment's K.E≈30KJ
- 0.5" AP K.E≈16KJ





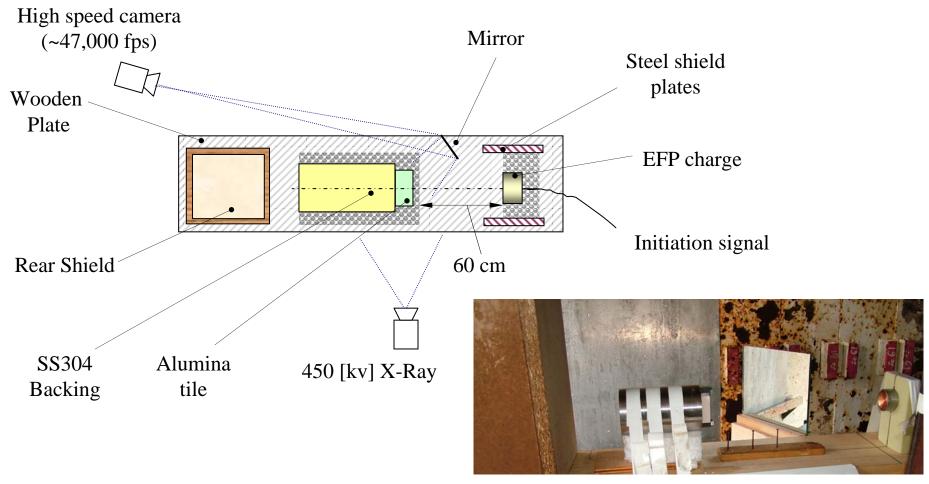
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Detailed Experimental setup



6 5/2009





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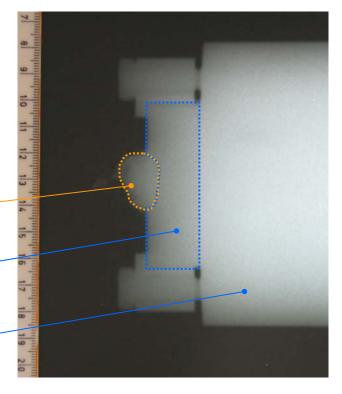
X-Ray

- A 450 [kv] Scandiflash X-Ray was used in order to examine the penetration process.
- 1st exp. flash time: 206 μs
- 2nd exp. flash time: 210 μs
- Parallax ratio = 0.83

Fragment during penetration

Alumina tile

Steel backing

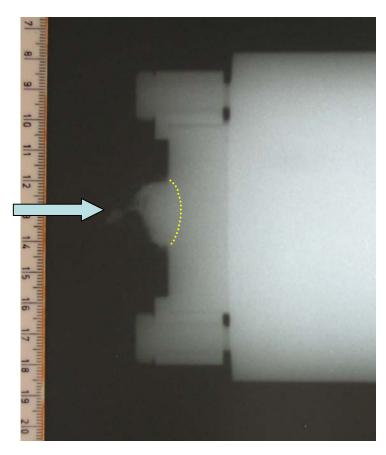




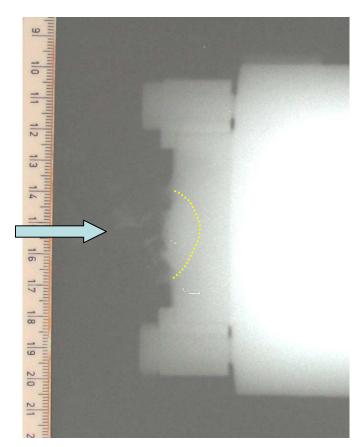


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Experiments Results – cont.







210µs

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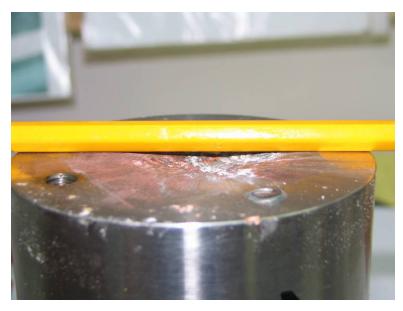




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Experiments Results

- Two Experiments were conducted.
- 1st experiment D.O.P. = **3.4** [mm]
- 2nd experiment D.O.P.= 3.7 [mm]





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Simulation Methods

- Autodyn v6.1 2D Lagrange solver has been used.
- Grid size convergence graph was done in order to optimize grid size and results convergence with computing resources.
- Parametric simulations were conducted, in order to evaluate different parameters and compare different constitutive models.
- Finally, fine grid size simulations were conducted on the chosen set of parameters.





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Simulation Modeling- Materials

Part	Material	Equation of state	Strength Model	Failure Model	Source
Ceramic Tile	Alumina (98%)	Polynomial	Johnson Holmquist	Johnson Holmquist	Westerling and Lundberg (1995)
Fragment	Copper	Linear	Johnson Cook	Johnson Cook	Johnson and Cook (1985)
Backing	SS304	Shock	Steinberg Guinan	-	Steinberg (1991)

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Simulated fragment penetration-Half problem



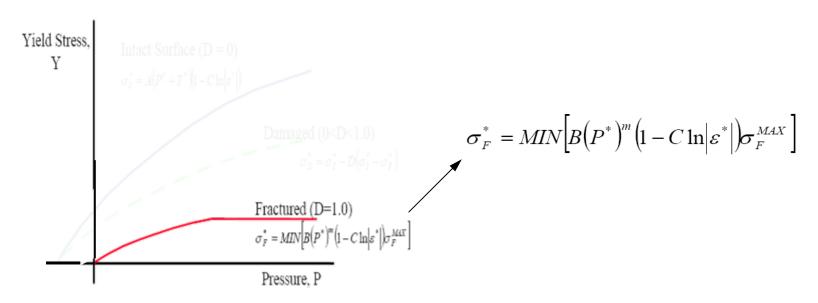




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Alumina Modeling- J-H strength model

- Parameters that were investigated: Fractured Curve
 - B slope of fractured curve
 - σ^f_{MAX} dimensionless fractured strength upper limit|_@D=1



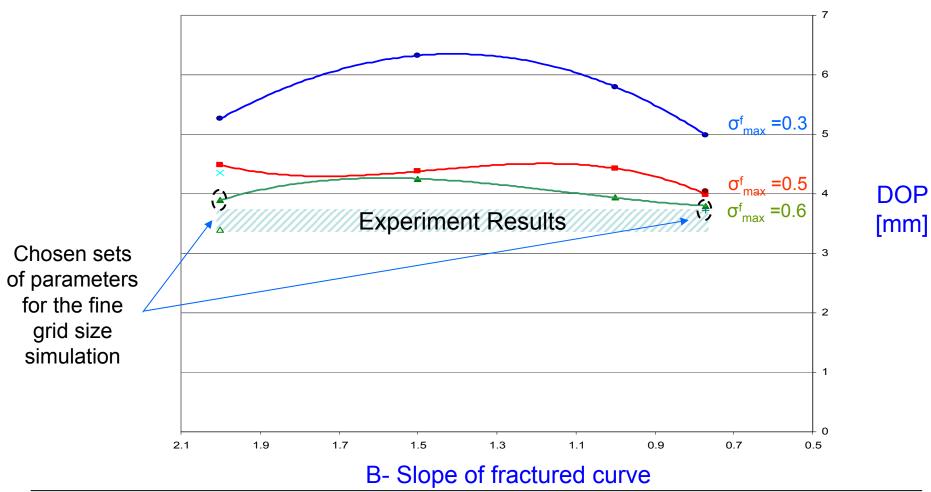
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Parametric Simulations results







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Literature Survey

Source	Alumina	Code	В	$\sigma_{\text{max}}^{\text{f}}$
Westerling et al. (1995)	99.7%	AUTODYN 2D (Lagrange)	0.77	0.5
Anderson et al. (1995)	99.5%	EPIC (SPH)	0.28	1
Lynch et al. (2006)	97.5%	Grim 2D (Euler)	0.86	0.5
Present work	98%	AUTODYN 2D (Lagrange)	0.77 Or 2	0.6

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Discussion

- Original J-H model (JH2) gives good estimation of the D.O.P experimental results.
- For an exact match, a modification of the fractured material parameters is presented (σ_{max}^f , B).
- The 'σ^f_{max}' Parameter has a strong influence on the D.O.P results. Nevertheless, 'B' parameter doesn't show a directional trend.





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Summary & Conclusions

- Two firing experiments were conducted in order to acquire D.O.P results.
- Experimental D.O.P results were compared to the corresponding simulations results.
- Simulations were carried out using Autodyn v6.1 2D Lagrange solver.
- A set of parameters were chosen (JH2 model) in order to match the experimental results.





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Future work....

- Further experiments on the same armor:
 - 1600 [m/s] fragment
 - 2500 [m/s] fragment
 - Bullet Impact
- Weight optimization (backing) for the armor is needed for commercial use.





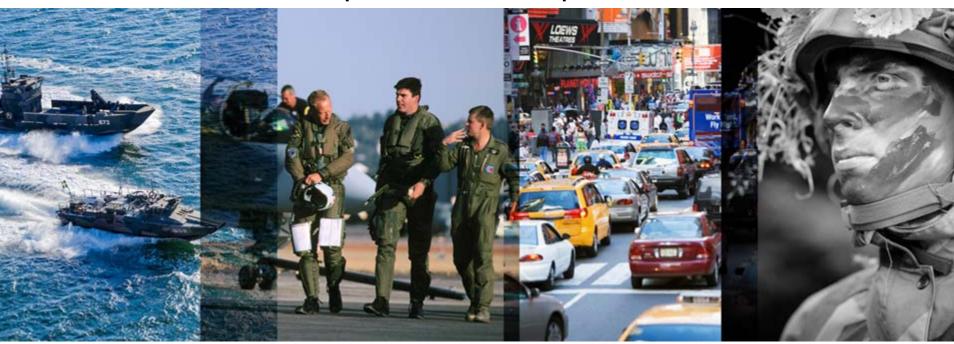
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The End



Propellant Blast Suppressive Transportation Box

A cost effective way to improve the IM-signature of rounds packed in transport boxes



Jon Toreheim
Saab Bofors Dynamics AB
May 13, 2009
2009 IM/EM Technology Symposium
Tucson, AZ

The 84 mm Carl-Gustaf system



- Recoilless, multi-role, man-portable weapon
- Can be used in almost any combat situation, such as:
 - Defeat MBTs
 - Destroy bunkers
 - Fighting soft targets
 - Close-in protection in jungle or built up areas
 - Create smoke effects
 - Illuminate target areas
 - Provides realistic and cost-effective training





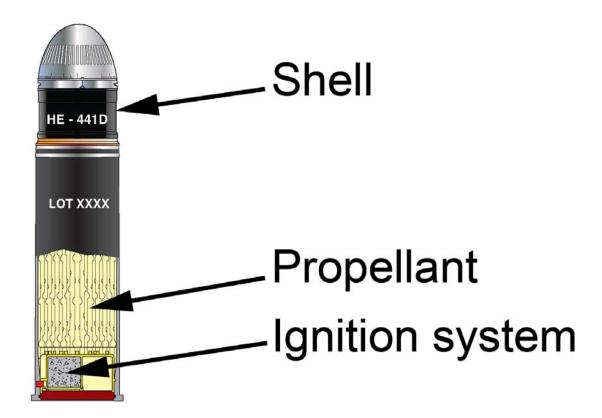






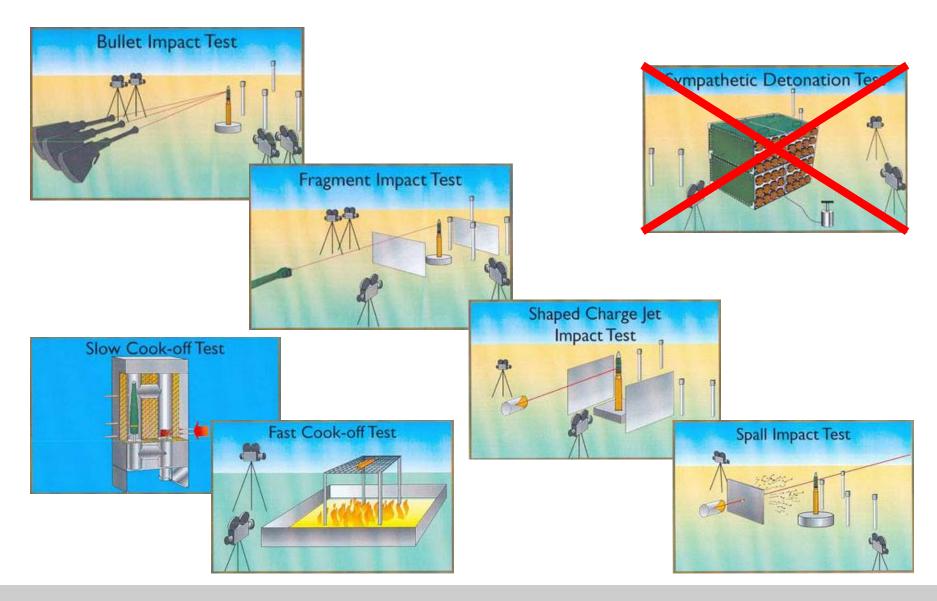


A typical 84 mm Carl-Gustaf round without rocket motor (HE 441D)





Problems...





Possible solution?



Today

Type IV reaction



Tomorrow

Type V reaction?



The Propellant Blast Suppressive Transportation Box (PBSTB)

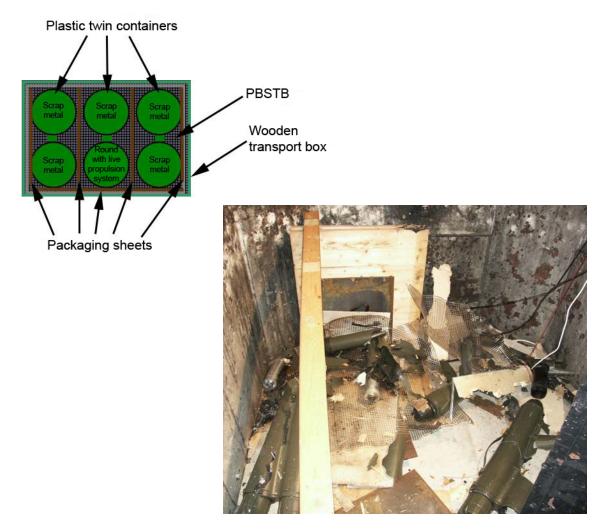


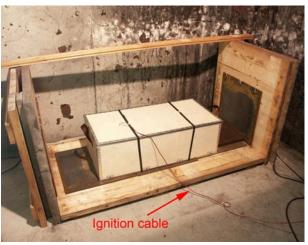


The first design concept



Let's test it!







The Propellant Blast Suppressive Transportation Box (PBSTB)



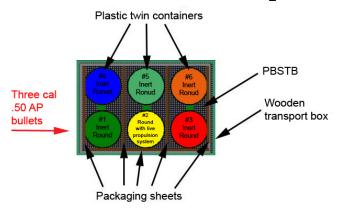


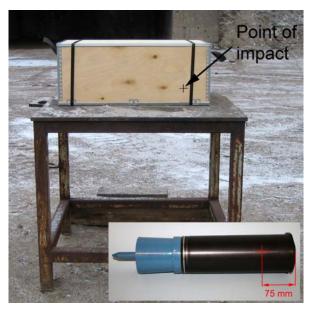


The latest design concept



Bullet Impact Test

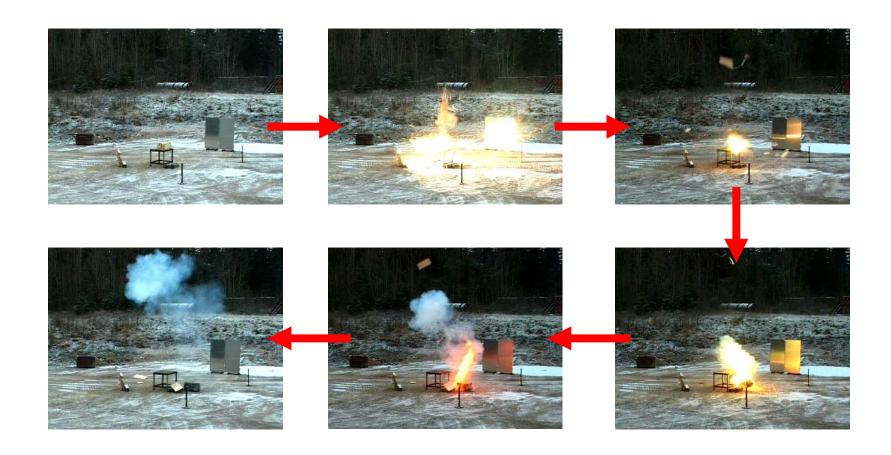






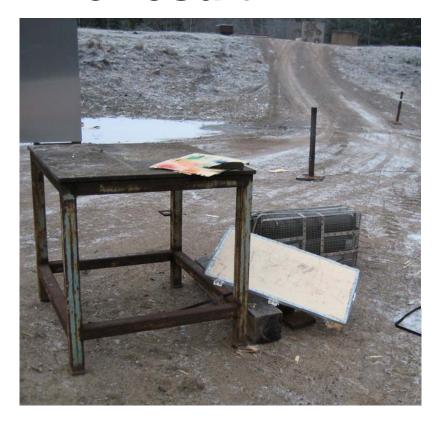


What happened?





The result





Type V reaction



The way forward...



Bullet Impact



Fast Cook-Off



Slow Cook-Off

...means more testing



Acknowledgements

- This work has been performed together with:
 - Peter Fritiofsson
 - Alf Prytz
- Other persons involved have been:
 - Björn Isaksson
 - Leif Jilsmo
 - Per Karlsson
 - Richard Lindvall
 - Henric Magnusson
- All of us work for Saab Bofors Dynamics AB



Questions?





Thank you!





SAABGROUP.COM



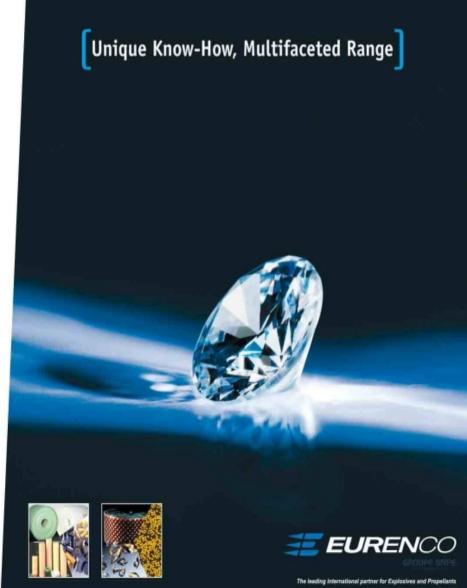
The leading international parmer for Explosives and Propellants

Insensitive Enhanced Blast Formulations

P.Chabin, B.Nouguez, B.Mahé EURENCO

C.Collet, SME

JM.Lesprit, A.Nouel MBDA/F







> CONTENTS

- > Objective / Framework
- \triangleright *E*nhanced *B*last e*X*plosive (EBX) overview
- > Explosive formulations pre selection
- ➤ Blast Characterizations
- ➤ IM Behavior assessment
- > Conclusions





1) Objectives

- > Framework:
 - Preliminary study
 - Cast PBX Formulations/ Architectures
- ➤ Target: Small or medium caliber ammunitions (\$\phi\$ max 125 mm)
- ➤ Goal: Balance between EBX performances increase and preservation of low vulnerability characteristics
- > Method:
- Step 1 : Bibliography
- Step 2 : Simple Thermo chemical calculations
- Step 3 : Testing
- Step 4: IM assessments with Databases and SME/EURENCO background





2-1) Cast PBX Overview: Formulations

> EBX = Energetic charge + Oxidizer + Reducer metallic particles + Binder (I or E)

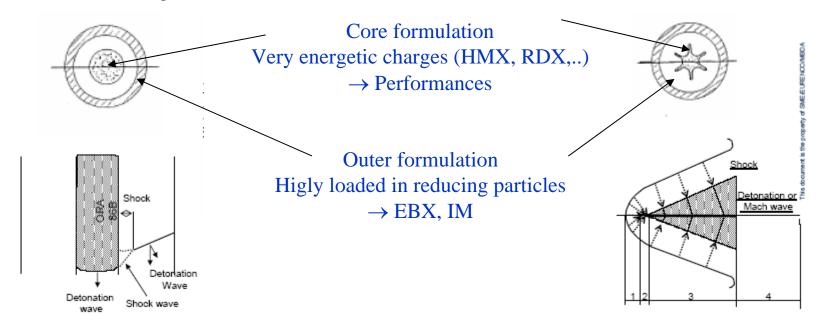
REFERENCES	COMPOSITIONS	APPLICATIONS			
AFX 757	RDX/AP/Al/HTPB	JASSM			
PBXN 113	HMX/Al/Inert binder				
PBXIH-135	HMX/Al/HTPB	BLU118/B, SMAW NE			
Existing EURENCO references					
B2211D	RDX/AP/Al/HTPB	Anti-runway, underwater warhead			
B2249	HMX/AP/Al/HPTB	Underwater warhead			
B2237	HMX/AP/AL/HTPB	Performances / IM characteristics			
B2242	HMX/Al/HTPB	Missile warheads			
B2258B	RDX/PA/Alu/PBHT	General purpose bombs - penetrators			
B3108B HMX/Al/Energetic binder		Missile warheads			





2-2) Cast PBX Overview: Architectures

➤ Use of dual charge formulation (EURENCO Patent)



- > Example :
- BIPS Penetrators : EURENCO formulations for core and outer explosives : B2237/B2250





2-3) Cast PBX Overview: Conclusions

Choice of

> Energetic charges

: RDX, HMX with AP or AL particle size centered on some µm

➤ No nanoscale particle : Cost / No EBX demonstration at this day

> Inert binder

: HTPB type for Economic reasons

➤ Advanced binder

: Facilitate the reaction of Al oxidation

> Cylindrical Dual composition Architecture : Economic reasons





3-1) Explosive formulations pre selection: Presentation

Mono Compositions

REFERENCES	COMPOSITIONS	
AFX 757	RDX/AP/Al/HTPB	
PBXIH-135	HMX/Al/HTPB	
B2211D	RDX/AP/Al/HTPB	
B2249	HMX/AP/Al/HTPB	
B2237	HMX/AP/AL/HTPB	
B2242	HMX/Al/HTPB	
B2258B	RDX/AP/Al/HTPB	





3-2) Explosive formulations pre selection: Presentation

Dual Compositions

CORE FORMULATION	OUTER EXPLOSIVE	COMPOSITIONS
	B2211D	RDX/AP/Al/HTPB
	B2249	HMX/AP/Al/HTPB
	B2242	HMX/Al/HTPB
ORA86B HMX/Inert binder	C1	Al/RDX/HTPB
	C2	Al/RDX/Advanced binder
	C3	Al/AP/HTPB
	C4	Al/AP/Advanced binder

- ➤ Mono / Dual Compositions : \$\phi\$ 125 h 125 mm samples
- \triangleright Dual compositions : core diameters : ϕ 50, 63 and 75 mm





3-3) Explosive formulations pre selection: Calculations

Establish a relative ranking between the various compositions

➤ Use of CHEETAH v2.0

• First alternative : CJ T°/ Energy released by adiabatic drop

of detonation products

• Second alternative: T°/P balance calculations to constant

volume in the air

- > Assumptions :
 - No kinetic law for the components reaction
 - Particle size not taken into account
 - Samples geometry not taken into account
 - Critical dimensions : post calculation analyses
- Comparisons with TNT references





3-4) Explosive formulations pre selection: Results

> Choice of a criterion of total performance to help in the classification

$$\xi = \sum_{i=1,4} \frac{x_i - \overline{x}_i}{\overline{x}_i}$$

x_i: Energy E, Tcj, P and T at the equilibrium (cst volume)

 ξ : emphasize compositions which present the most positive variations (cumulated way)

> Results:

• Mono compositions : 1- B2211D, 2-B2258B and 3-B2237

• Dual compositions : 1-Outer B2211D, 2-B2249 and 3-B2242

• Highly outer formulation : 1-ORA86B/C2 formulation

> Critical dimensions analyses :

• Mono compositions: Choice of the B2258B instead of the B2211D

• Dual compositions : Core diameter : ϕ 63 (no significant gain with ϕ 75)

• Highly outer formulation : Core diameter ϕ 75 mm





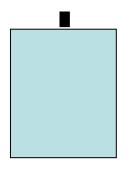
3-5) Explosive formulations pre selection: Conclusions

- ➤ CHOICE n°1 : MONO COMPOSITION B2258B
- ➤ CHOICE n°2: DUAL COMPOSITION \$\phi\$ 63 mm ORA 86B / B2211D
- ➤ CHOICE n°3 : DUAL COMPOSITION \$\phi\$ 75 mm ORA86B / C2



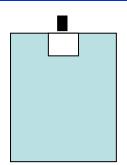


4-1) Blast Characterization: Presentation



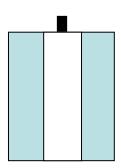
B2238

Mass: 2350 g



B2258B With ORA86B Φ 50 H 30

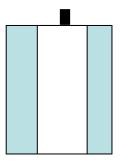
Mass: 2600 g



ORA86B Φ 63 H 125

B2211D

Mass : 2730 g



ORA86B Φ 75 H 125

C2

Mass : 3270 g

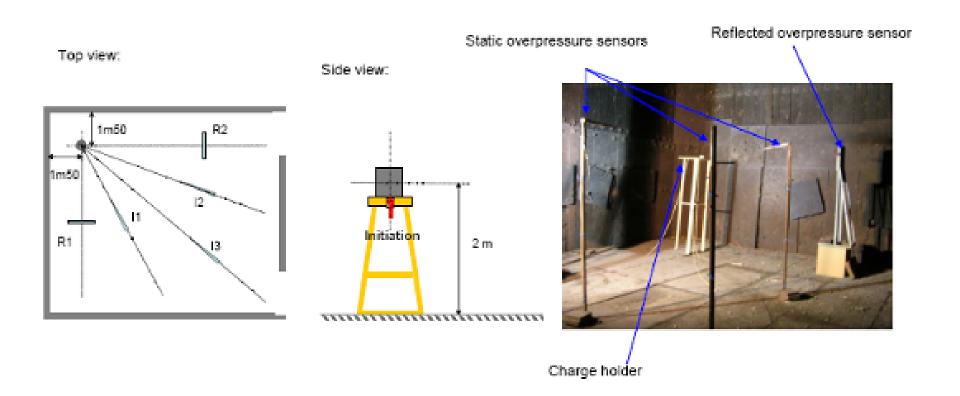
All external dimensions: \$\phi\$ 125 h 125 mm

- ➤ B2238A : RDX/PBHT : Reference composition
- ➤ Shot n°1 : Reference composition (bare configuration)
- ➤ Shot n°2, 3 and 4 : Selected compositions in bare configurations
- > Shot n°5: Most promising formulation or/and configuration with 5 mm Aluminum confinement





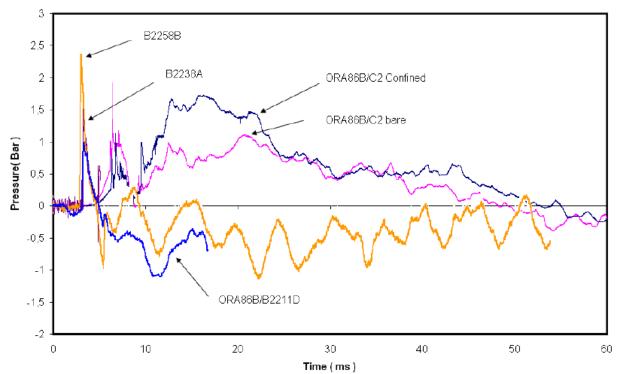
4-2) Blast Characterization: Experimental configuration







4-3) Blast Characterization: Results



Example of static overpressure measurements

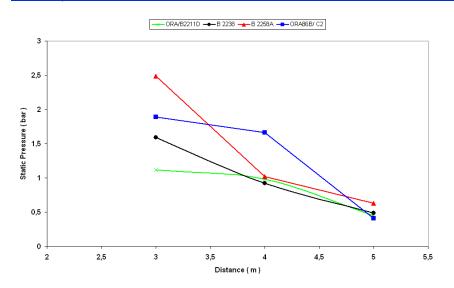
Test chamber after shot with ORA86B/C2 arrangement

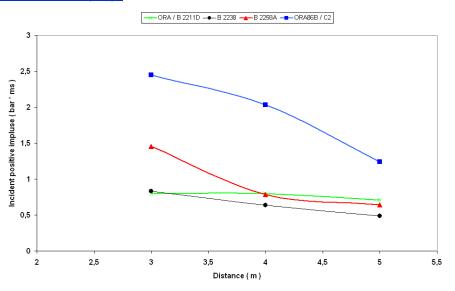






4-4) Blast Characterization: Results(2)





COMPOSITIO	ONS	Pressure TNT Eq. (3m)	Impulse TNT Eq. (3m)	Pressure TNT eq. (4m)	Impulse TNT Eq. (4m)	Pressure TNT eq. (5m)	Impulse TNT Eq. (5m)
B2238A sho	ot 1	1,49	1,49	1,42	1,42	1,22	1,34
B2258B sh	ot 2	2,23	3,26	1,46	1,83	1,46	1,86
ORA86B/B2211D	shot 3	0,67	1,19	1,05	1,76	0,75	2,05
ORA86B/C2	shot 4	1,25	3,80	2,4	2,2	0,49	1,50





4-5) Blast Characterization: Conclusions

➤ Overpressure best choice : B2258B

➤ Positive impulse "short duration ": ORA86B/C2

<u>But :</u>

➤ Long duration overpressure/impulse: ORA86B/C2 (EBX and TBX ?)

- ➤ Need to:
 - Improve instrumentation "Ballistic measurement"
 - Optimize ratio between ORA86B and C2
 - Test different test chamber volumes





5) IM Assessments

	B2258B	B2211D	ORA86B
ISGT	130 cards	80 cards	160 cards
ELSGT	90 mm	50 mm	90 mm
Friability	12.4 Mpa/ms	3.8 Mpa/ms	5 MPa/ms
ESD	No sensitive	No sensitive	No sensitive
Self ignition T°	212 °C	213 °C	245°C
Bullet Impact		V	IV-V
Fast Cook Off		IV –V	
Slow Cook Off		IV- V	IV-V
Sympathetic detonation	III /IV		

Estimated IM Signature for a warhead

	FCO	SCO	BI	SD	SCJ
B2258B	V	V	NR à IV	III/IV	III à I
ORA86B/C2	V	V	NR à V	III/IV	III à I





6) Conclusions

- ➤ Preliminary study performed with the goal to choose the best compromise between EBX effect increase and low vulnerability characteristics for small/medium caliber ammunitions
- ➤ 3 formulations/architectures preselected after simple thermo dynamical calculations

• Mono composition : B2258B (RDX/AP/AL/PBHT)

• Dual composition : ORA86B/B2211D

• Dual composition : ORA 86B/C2

- ➤ Tests highlight excellent EBX behavior for ORA86B/C2, B2258B is also a good candidate especially regarding static overpressures
- ➤ Depending the final warhead configuration STANAG 4439 requirements could be achieved with these two formulations
- Results are very promising, the work is in progress with regard to:
 - Improvement on the geometry/architecture for the ORA86B/C2 arrangement
 - Improvement on instrumentation and experimental configuration



FOX-7 based Insensitive Cast PBX

C. Collet - B. Le Roux - B. Mahe - B. Nouguez

Contents

- Introduction
- FOX-7 Characteristics
 - Chemical and basic properties
 - Safety results on raw material
- Formulation Works
 - Preliminary Study
 - Feasibility and Safety Results
- Experimentations
- Conclusion





- EURENCO and the French Research Centre of SNPE Group are working together to manufacture new cast Plastic Bonded explosives (PBXs):
 - More and more powerful
 - Less and less sensitive
 - And cost effective, of course!
- ☐ FOX-7 is known for:
 - its detonation properties close to the ones of RDX
 - its low sensitivity on raw material and in pressed and melt poured High Explosives
- QUESTION: what would be the result of introducing FOX-7 in a cast PBX ?
- ☐ The composition chosen to support this study is the PBXN-109, well known for its low shock sensitivity: 140 acetate cards at French Large Scale Gap Test
- ☐ The French version of PBXN-109 contains :

I-RDX® : 64 %Aluminum : 20 %

• Inert binder : 16 %





Introduction (2/2)

■ Methodology of this study

Raw material

Safety results

PBXN-109 containing I-RDX® : I-PBXN-109

PBXN-109 containing FOX-7 : F-PBXN-109

Composition

Safety results

Shock sensitivity and detonation performances



May 11-14, 2009

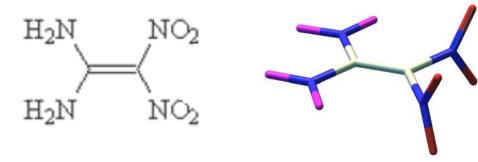
Contents

- Introduction
- ☐ FOX-7 Characteristics
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FOX-7 Characteristics

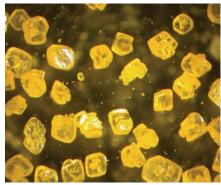
☐ Chemical Formula of FOX-7 molecule



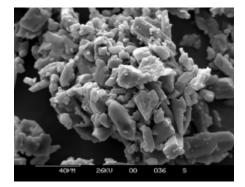
■ Aspect of FOX-7 crystals



FOX-7 powder



Microscopy picture



SEM picture



IMEMTS 2009, Tucson (AZ)

May 11-14, 2009



■ Thermochemical and Detonation properties

	FOX-7	RDX
Crystal density (g/cc)	1.885	1.806
Heat of Formation (kcal/mol)	-32.0	-16.5
Activation Energy (kcal/mol)	58	40
Theoretical Det. Velocity (m/s)*	8849	8940
Theoretical Det. Pressure (GPa)*	33.7	34.6

^{*} from CHEETAH v2.0 calculations

The detonation properties of raw FOX-7 are expected to be very close to the ones of raw RDX





☐ Safety Results on raw material

	FOX-7	RDX
Friction Sensitivity (ISF*)	> 350 N	120 N
Impact Sensitivity (ISI**)	20 - 40 J	4 - 5 J
Sensitivity to ElectroStatic Discharge (ESD)	Not sensitive	Not sensitive
Auto Ignition Temperature	215°C	223°C

^{*} corresponding to the French norm AFNOR NF T70-503

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FOX-7 clearly appears less sensitive than RDX at impact and friction



^{**} corresponding to the French norm AFNOR NF T70-500

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Preliminary Study

■ Estimation of Detonation properties for both compositions with the help of CHEETAH v2.0

	F-PBXN-109	I-PBXN-109
Density (g/cc)	1.703	1.665
Detonation Velocity (m/s)	7018	7074
Detonation Pressure (GPa)	18.85	19.38
Energy @ V/V0 = 2 (GPa cm ³ / cm ³)	4.30	4.63
Energy @ V/V0 = 7 (GPa cm ³ / cm ³)	6.63	7.11

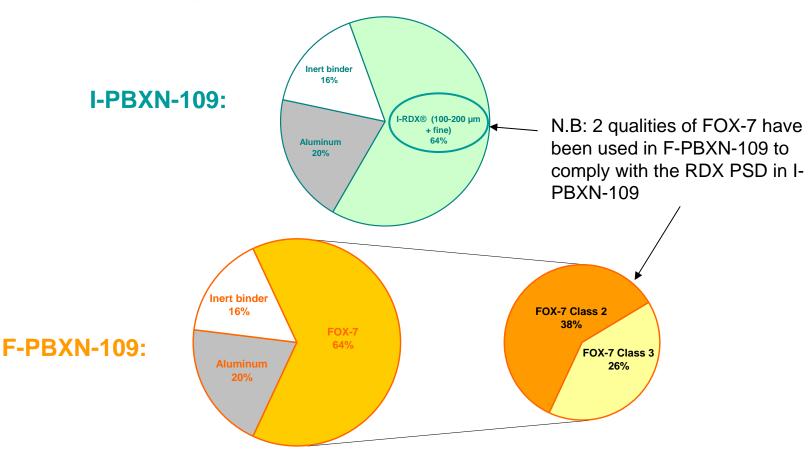
The use of FOX-7 in PBXN-109 leads to equivalent detonation performances than standard PBXN-109 containing RDX



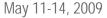


Formulation Works

☐ The total mass of RDX in PBXN-109 (64 wt%) has been substituted by the same mass of FOX-7:







Formulation Works

■ Safety Results

Back to safety res. on raw material

	F-PBXN-109	I-PBXN-109
Friction Sensitivity (ISF)	> 353 N	> 353 N
Impact Sensitivity (ISI)	> 50 J	26 J

- → No more sensitivity difference at friction
- → F-PBXN-109 is less sensitive than I-PBXN-109 at impact
- □ 5 cylinders Ø 40 H 200 mm of F-PBXN-109 were cured to evaluate:
 - Shock Sensitivity at Large Scale Gap test (LSGT)
 - Detonation Velocity





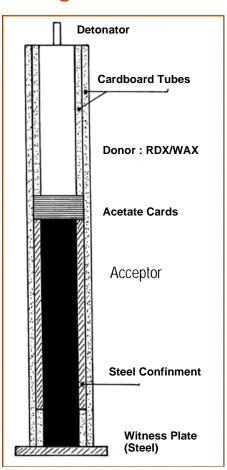
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Experimental set up for LSGT

■ Description of French Large Scale Gap Test (LSGT) according to STANAG 4488 annex B





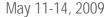
Donor: RDX/Wax Ø 40 mm

Barrier: acetate cards 0.19 mm thick. The result is the number of cards which does not transmit the detonation to the acceptor

Acceptor: Ø 40 H 200 mm in a steel confinement 4 mm thick



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Results

☐ F-PBXN-109 results and comparison with I-PBXN-109:

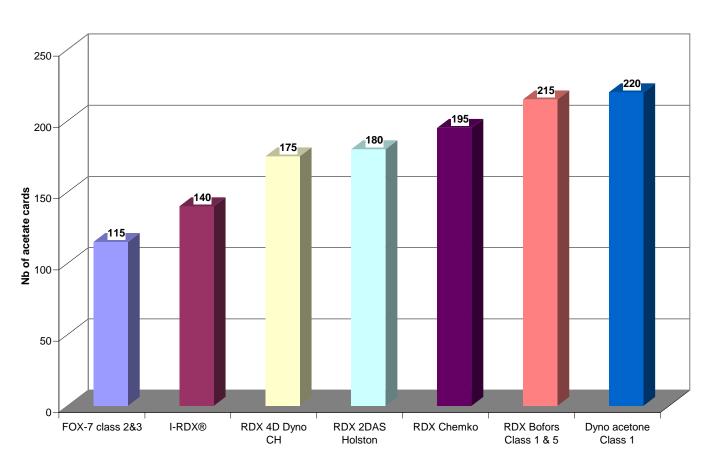
	F-PBXN-109	I-PBXN-109
Crystal quality	FOX-7 class 2&3	I-RDX®
Detonation Velocity (m/s)	7300 ± 50	7527 ± 38
LSGT Result	115	140 ± 5
Pressure in acetate (kbar)	68.2	53.7

- → The Det. Velocity of F-PBXN-109 is 3% lower ...
- → ... but the initiation pressure is **27** % **higher**



Results

☐ Comparison with PBXN-109s containing miscellaneous qualities of RDX







IMEMTS 2009, Tucson (AZ)

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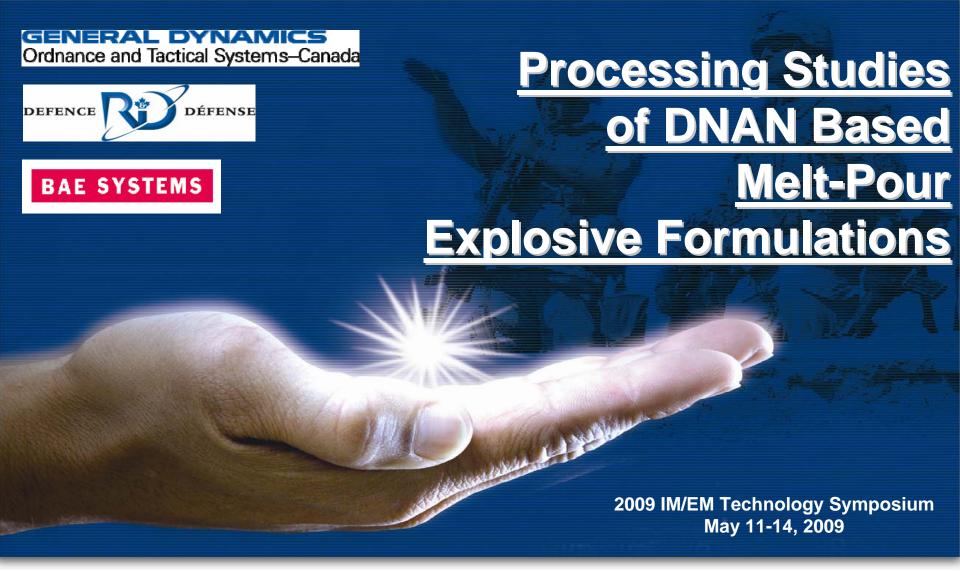


Conclusion

- □ A cast Plastic Bonded explosive containing FOX-7 has been successfully realized
- □ Comparing to regular PBXN-109, the "PBXN-109 like" composition containing FOX-7 exhibits:
 - Equivalent or lower sensitivities to standard safety tests
 - Equivalent detonation properties
 - A significant improvement of shock sensitivity
- □ These first results concerning the introduction of FOX-7 in a cast PBX are very promising for the industrial development of new Extremely Insensitive Detonable Substances (EIDS)







Pierre Pelletier, Isabelle Laroche, Daniel Lavigne, Frank Cantin: GD-OTS Canada

Patrick Brousseau: DRDC-Valcartier

Virgil Fung: BAE Systems OSI

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Introduction and Background



- ➤ Until recently, Insensitive High Explosive (IHE) formulations used in Insensitive Munitions (IM) were mainly cast-cured or pressed formulations.
- ➤ New developments in melt-poured IHE and work that showed that they could also have good IM properties revived the interest for the type of explosive processing.
- ➤ GD-OTS Canada (formerly SNC TEC) has more than 60 years experience with TNT-based formulations, as well as some experience with PAX-21, PAX-25 and PAX-34 DNAN-based formulations.
- The objective of this presentation is to present the tests performed on two dinitroanisole (DNAN) based formulations (OSX-7 and OSX-8) as well as the results obtained.

Formulations Tested



- > OSX-7: DNAN, NTO, RDX
- > OSX-8: DNAN, NTO, HMX
- > Reference formulations:
 - Composition B: 59.5% RDX, 39.5% TNT, 1.0% wax
 - PAX-34: DNAN, NTO, TATB, HMX
- > Components:
 - DNAN: Dinitroanisole
 - NTO: 3-nitro-1,2,3-triazol-5-one
 - HMX: Octogen
 - RDX: Hexogen
 - TATB: 1,3,5-triamino-2,4,6-trinitro benzene

Viscosity and Sedimentation Testing



- > Viscosity and particle size distribution of the solids are important characteristics for melt-pour formulations.
- ➤ A high viscosity can impair mixing and pumping operations and can lead to more air entrapment during loading.
- ➤ A low viscosity can also affect air entrapment and enhances solid particles settling in the equipment and in the loaded shell bodies.
- GD-OTS Canada series of characterization tests are used to evaluate the formulation viscosity and the tendency of its solid particles to settle.



- ➤ The test is performed using a double jacket heated pot containing 1.5 kg of material with a Brookfield viscometer equipped with a "A" T-shaped spindle rotating at 20 RPM.
- > Viscosity measurements taken after 0, 7.5 and 15 minutes.
- ➤ In between measurements, the material is allowed to settle freely, without being agitated.
- ➤ The test temperature is maintained throughout the test duration.





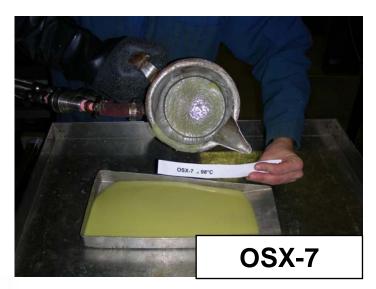
> Viscosities measurements

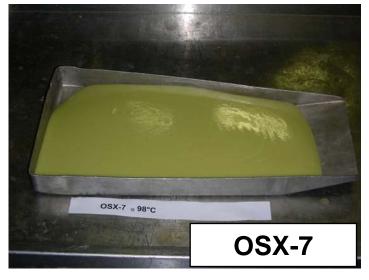
Formulations	OSX-7	OSX-8	PAX-34	Comp B
Test temperature	98°C (208°F)	98°C (208°F)	98°C (208°F)	93°C (199°F)
Initial viscosity (cP)	3040	1440	880	700-1000
Viscosity after 7.5 minutes (cP)	3286	1520	1040	1000-1400
Viscosity after 15 minutes (cP)	3440	1680	2720	2000-2400



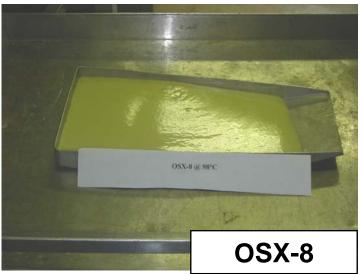
- > The viscosity test is immediately followed by the sedimentation test.
- > The material in the heated test pot from the viscosity test is poured onto a pan and observations are made on
 - The way the material flows
 - The amount of material remaining in the test pot
 - The way the material places itself on the pan
- OSX-7: appears homogeneous and flows steadily.
- OSX-8: Visual segregation of constituents visible during pouring. It is very liquid at first and more viscous towards the end.





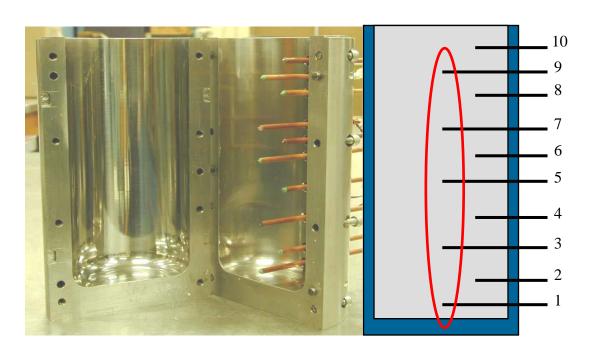








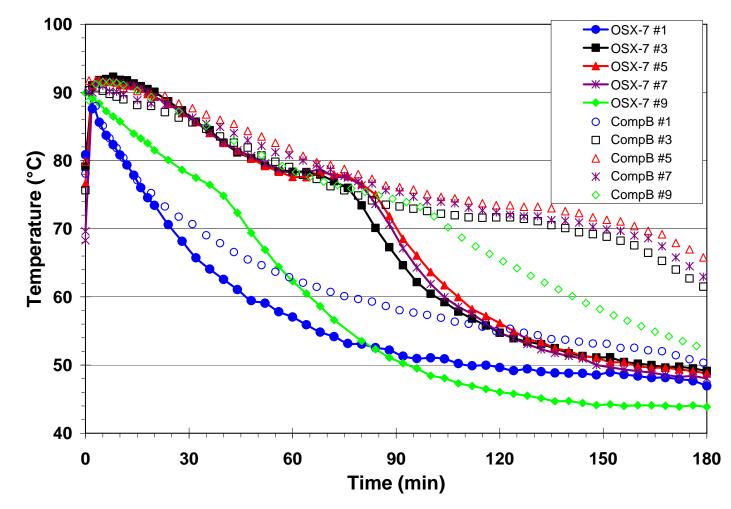
- > With melt-poured formulations, controlled solidification is required to prevent formation of defects in the cast.
- ➤ The thermal behaviour is studied using a split mould cylinder loaded with the formulation. The temperature profile is recorded and material shrinkage is observed.





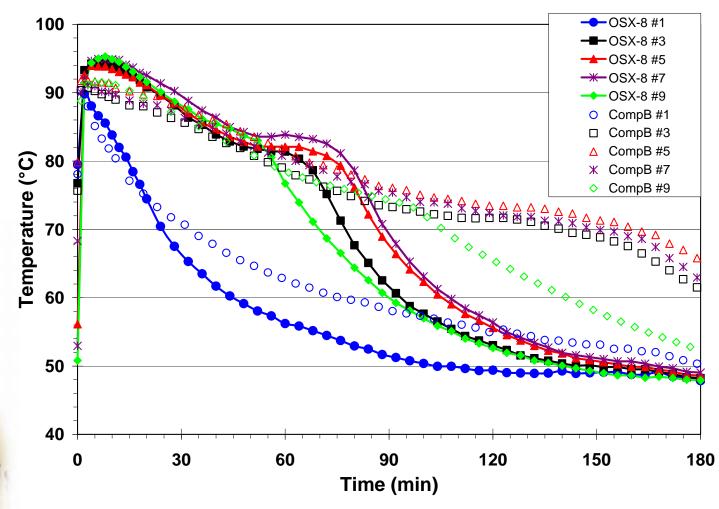


> OSX-7 − Center Thermocouples





> OSX-8 - Center Thermocouples





- ➤ OSX-7 and OSX-8 cool and solidify much faster than Composition B
- > The charges were removed from the split-mould cylinder and sectioned along their longitudinal axis.
 - Both OSX-7 and OSX-8 shrink less than Composition B. The charge had a large cavity with a diameter of ≈35 mm and other small cavities below the central cavity.





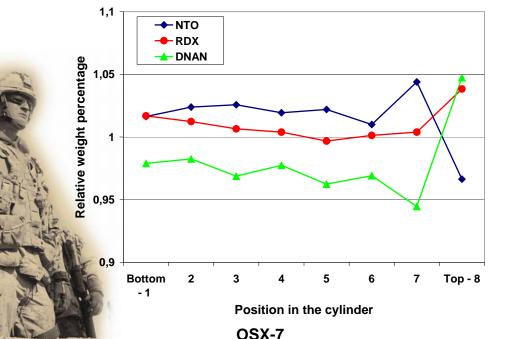


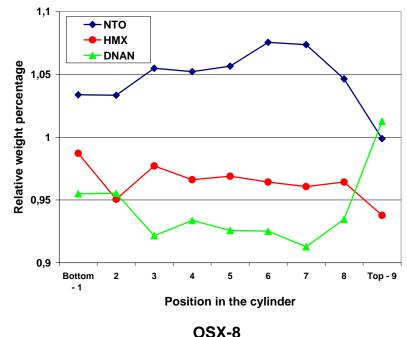
OSX-7 OSX-8

Sedimentation studies



- ➤ Relative percentages of components from samples taken in the thermal characterization cylinder compared to the initial values in the composition.
 - OSX-7 is more viscous leading to less variations
 - Ingredients variations are small compared to composition B



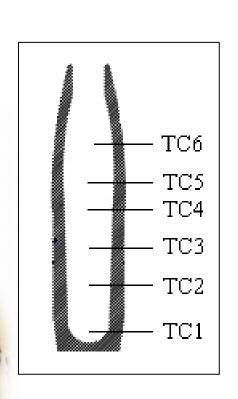


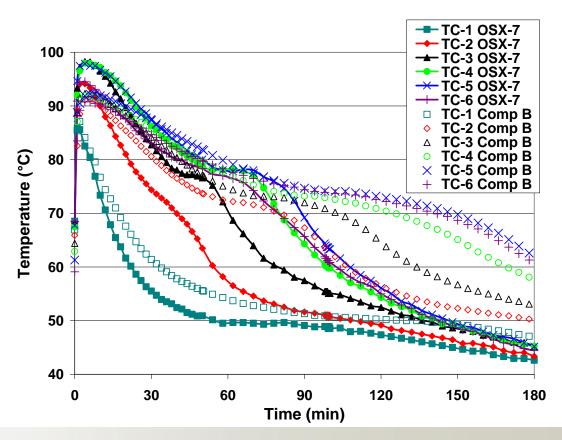


- ➤ 105 mm HE M1 shells were loaded using standard process conditions, but at a higher loading temperature for OSX-7 and OSX-8.
- ➤ A shell body instrumented with 6 thermocouples (located at 1.2, 3.7, 5.7, 7.7, 9.2 and 11.2 in from base) was included to record the cooling temperature profile.
- ➤ Radiographic inspection was performed on the loaded shell bodies.



➤ OSX-7: Formulation solidifies much faster than composition B (60 minutes faster).







> OSX-7: Filling results

- Good filling quality free of major casting defects with only minimal adjustments of composition B parameters and no change to the equipment.
- Strong wall adherence in the bottom section.
- Minimal acceptable cavities to be solved in future DOE studies

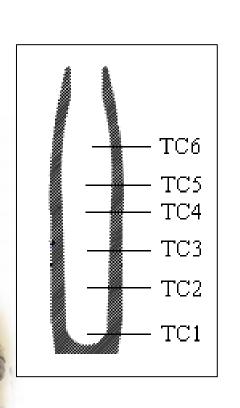


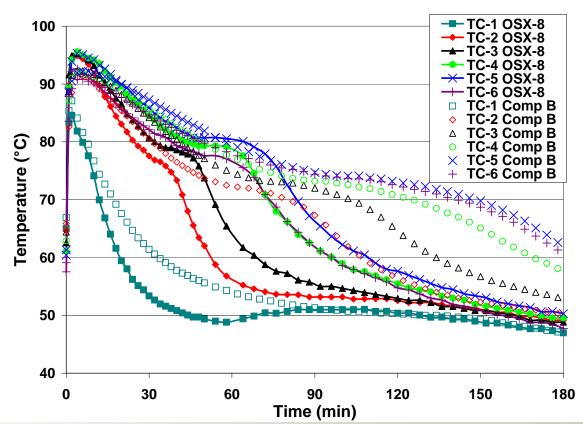






➤ OSX-8: Formulation solidifies much faster than composition B and similar to OSX-7 (60 minutes faster)



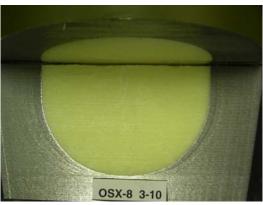




> OSX-8: Filling results

- Good filling quality free of major casting defects with only minimal adjustments of composition B parameters and no change to the equipment.
- Strong wall adherence in the bottom section.







Mechanical properties



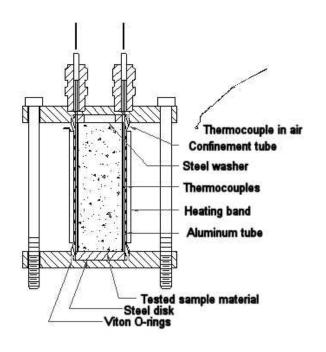
> Mechanical properties in compression

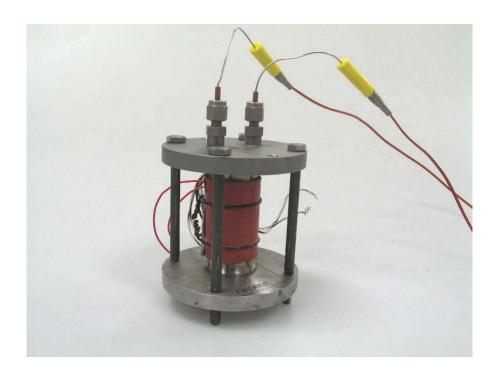
Property	OSX-7	OSX-8	Comp B
Maximum stress (S _m) [MPa]	18.9 ± 1.6	17.8 ± 1.3	8.1 ± 1.8
Strain at maximum stress (e _m) [%]	2.5 ± 0.3	2.5 ± 0.1	2.0 ± 0.3
Young's modulus (M) [MPa]	1708 ± 281	1436 ± 236	840 ± 147
Stress at rupture (S _R) [MPa]	9.5 ± 0.8	8.9 ± 0.7	4.0 ± 0.9
Strain at rupture (e _R) [%]	3.5 ± 0.4	3.3 ± 0.2	2.7 ± 0.1

Variable Confinement Cook-off Test



> VCCT equipment





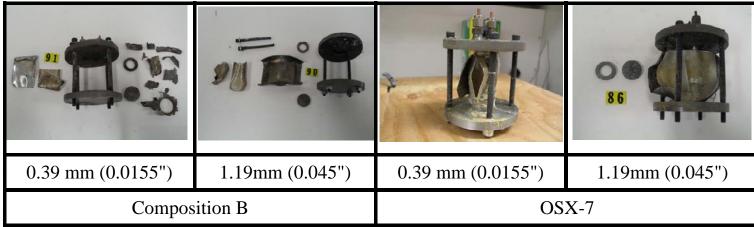
Variable confinement cook-off tests @



> Results

Composition	0.39mm (0.0155") confinement		1.19mm (0.045") confinement		
Composition	Reaction T°	Reaction type	Reaction T°	Reaction type	
OSX-7	182°C (360°F)	V	179°C (354°F)	V	
OSX-8	199°C (390°F)	V	199°C (390°F)	V	
Composition B	184°C (363°F)	III	183°C (361°F)	III	





Summary and Future work



- ➤ Two IM DNAN based melt-pour formulations (OSX-7 and OSX-8) were studied in GD-OTS Canada pilot plant equipment and characterized.
- ➢ Both OSX-7 and OSX-8 exhibit higher melting point, higher viscosity and faster crystallization but the actual GD-OTS Canada modified Meissner process can be used without modification to the equipment and minor adjustments to the parameters to fill projectiles as shown in studies on 105mm M1 filling.
- ➤ Both OSX-7 and OSX-8 settle less than typical composition B.
- ➢ Both formulations present mechanical properties in compression about twice as good as composition B.
- Variable confinement Cook-off Tests indicate that OSX-7 and OSX-8 better withstand cook-off tests (burning vs explosion for the confinement tested)
- <u>Future work planned</u>: Additional characterization studies: detonation properties, physical properties during ageing, LSGT, filling of other projectiles, IM tests.

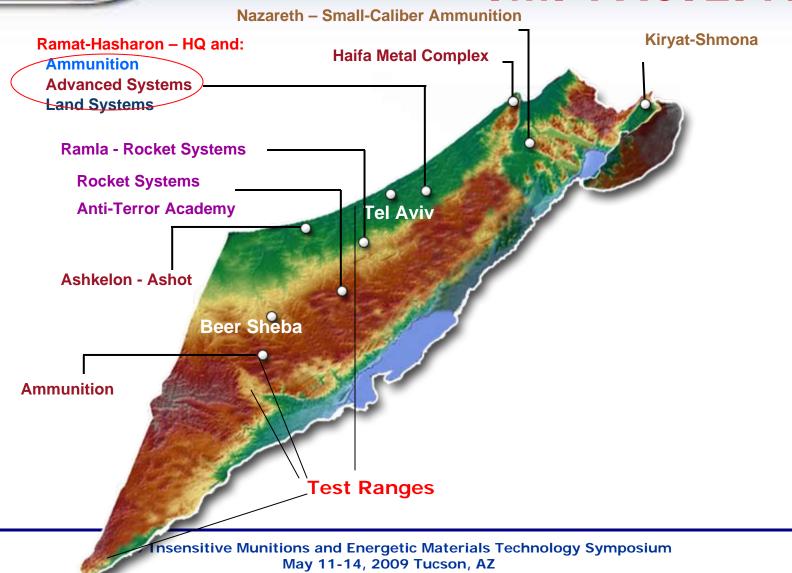




CLX 533 A new Insensitive High explosive

E. Shachar, A. Maish, G. Strul, I. Mandel, H. Rosentswieg

IMI FACILITIES

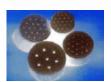


IMI Munitions System Division

Commitment for Safety and Performance







- Infantry and medium caliber
 - Air-to-Ground
 - Artillery









Outline of the presentation:

- ☐ Background.
- □ Objectives.
- ☐ Approach.
- Qualification Process.
- Summary.



Background





Tank & Artillery Ammo



IHE Compositions





CLX 663

CLX 851







IM Technologies in IMI



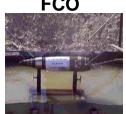


IM Testing

<u>Under Mil Std 2105 and stanag 4439</u>

FCO

- Fast cook-off (FCO)
- Slow cook-of (SCO)
- Bullet impact (BI)
- Sympathetic detonation
- Shape charge





IM Insensitive Munition

IM-Material



IHE Compositions 4

- CLX 663
- CLX 851

LOVA Propellant



OBJECTIVES

- The objective of this task was to introduce a new HE composition with high impulse and fragmentation features. Must have an output greater than PBXN-109.
- Comply to the definition of IHE and IM characteristics at least as good as CLX-663.
- Qualify the new composition for the IDF (Additional requirements).



Formulation & Production

- ☐ Down selection from several formulations.
- ☐ The composition is a bi modal high nitramine (HMX), Aluminum and HTPB Binder and additives.
- Nominal Density (97% TMD) of 1.8 g/cc for the cured material.
- ☐ Production of medium batches (100 Gal) at IMI-Chemical Plant.

The Approach of this task:

- ☐ Finalizing the Ingredients and composition.
- Determining the final ballistic requirements.
- Configuration of the final process production.
- ☐ Qualification of the composition according the IDF standards including an aging protocol.

Testing Protocol

- ➤ Hazard analysis Impact, Friction, ESD
- ➤ Thermal analysis.
- ➤ Mechanical properties.
- > Detonation and critical diameter.
- > EIDS tests : Cap test.

LSGT.

External Fire test.

Bullet Impact.

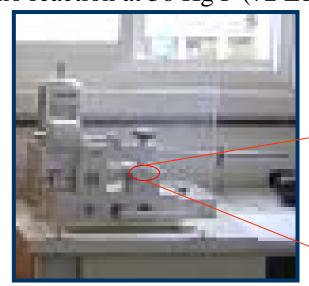
Hazard Characterization - Friction Sensitiveness

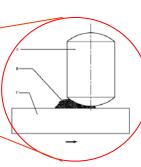
Requirement: Less sensitive than RDX and similar to CLX 663.

Method: MIL-STD-1751 Method 1024

Results: 20/20 consecutive negative tests - no reaction at 36 Kg F (72 Lb f)

Explosive	Friction Sensitivity [kgf]
CLX-533	No reaction (max 36)
	* No reaction (max 36)
Comp. B	No reaction (max 36)
CLX-663	No reaction (max 36)
	* No reaction (max 36)





^{*} After aging (28d, 95%RH, 70°C) – IDF requirement.

Hazard Characterization - Impact Sensitiveness

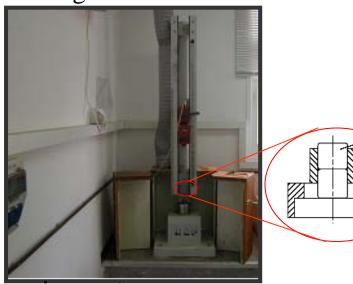
Requirement: Less sensitive than RDX and similar to CLX 663.

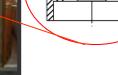
Method: MIL-STD-1751 Method 1101

Results: Impact results remain fairly consistent, results comparable to

RDX and CLX 663 - E $_{50\%}$ Bruceton method– 3.04 Kg m

Explosive	H 50% [cm]	Energy [kg m]
CLX-533	60.72 (5 kg)	3.04
	*66.83	*3.34
CLX-663	58.4 (5 kg)	2.92
	*50.12	*2.51
Comp B	50.1 (5 kg)	2.51





^{*} After aging (28d, 95%RH, 70°C) - IDF requirement.

Hazard Characterization - ESD Sensitiveness

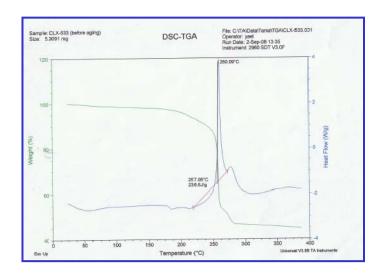
Requirement: 30/30 No Fires at 0.25 J

Method: MIL-STD-1751 Method 1032

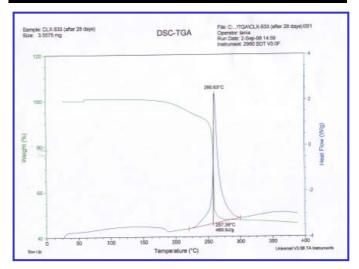
All results pass.



Thermal Analysis: DSC-TGA



Explosive	Self Ignition Temp.	
	[°C]	
CLX-533	257.1	
	* 257.4	
CLX-663	220.2	
Comp. B	232.5	



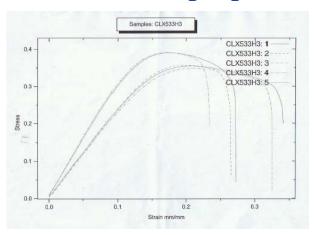
* After aging (28d, 95%RH, 70°C) - IDF requirement

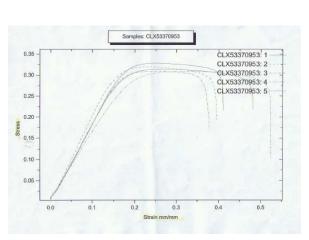
Vacuum Stability

This method is used to determining the energetic material stability by measuring the volume gas liberated of a heated sample under vacuum.

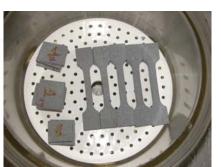
Explosive	Volume/gr (mm)	IDF Req.
CLX-533	0.17	
CLX-663	0.05	Less than 1 ml/gr
Comp B	0.24	

Mechanical properties









Before

	Area (cm*2)	Modulus (Kg/cm^2)	Stress at Max.Load (Kg/cm*2)	% Strain at Max.Load (%)	% Strain at break (%)
1	1,178	24.297	3.610	20.681	33.333
2	1,201	24.504	3.640	20.073	25.912
3	1.232	22.950	3.551	20,925	31.873
4	0.990	32.373	3.986	16.910	22.871
5	1.035	31.005	3.982	17.397	27.008
Mean	1.127	27.026	3.754	19.197	28.200
5.D.	0.108	4.326	0.213	1.899	4.327

40.003

14,049

4.392

3,116

24,895

13,499

41.181

15.218

* After aging (28d, 95%RH, 70°C) - IDF requirement.

1,450

0.804

2009 Insensitive Munitions and Energetic Materials Technology Symposium May 11-14, 2009 Tucson, AZ

Mean +3.00 SD

Mean -3.00 SD

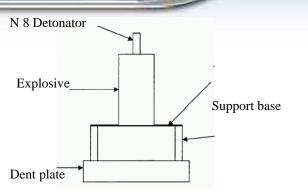
Detonation Velocity & Critical Diameter





Sample	Detonation Velocity (m/s)	Critical Diameter (mm)
CLX-663	7598	18.4
CLX-533	7389	14.8
Comp. B (cast)	7900	4.3*

^{*} MIL-STD-1751A



EIDS testing of CLX-533

Cap Test

Requirement: No detonation

Method: TB 700-2 Chapter 5-8 (UN Test 7 (a))

Results: No penetration through witness plate

This shock test is designed to determine the sensitivity of an EIDS candidate to intense mechanical stimulus.





2009 Insensitive Munitions and Energetic Materials Technology Symposium May 11-14, 2009 Tucson, AZ

Test results of the qualification process

EIDS testing of CLX-533



Large Scale Gap Test (LSGT)

Requirement: No clean hole punched through the

plate.

Method: TB 700-2 Chapter 5-8 (UN Test 7 (b))

Results: Dents in witness plates



The test is used to predict the sensitivity of an EIDS candidate, under confinement in a steel tube, to a specified shock level i.e. a specified donor charge and gap.

Test results of the qualification process

EIDS testing of CLX-533





External Fire Test

Requirement: No detonation, no fragment > 1 gram,

> 15m

Method: TB 700-2 Chapter 5-8 (UN Test 7 (e))

Results: All parts remained in place. Explosive

burned inside the tubes.

This external fire test is used to determine the reaction of an EIDS candidate, to external fire when it is confined.

Test results of the qualification process

EIDS testing of CLX-533





Bullet Impact

Requirement: No explosion or detonation.

Method: TB 700-2 Chapter 5-8 (UN Test 7 (d))

Results: 9/10 Explosive scattered.

1/10 Explosive burned inside the tube.

The bullet impact test is used to evaluate the response of an EIDS candidate to the kinetic energy transfer associated with impact and penetration of a given energy source, i.e. a 12.7 mm projectile, traveling at a specified velocity ($840 \pm 40 \text{ m/s}$).

Conclusions & Summary

- ☐ IMI has introduced a new and powerful IHE CLX 533.
- ☐ According to the tests results described above IMI CLX 533 formulation was designated as Insensitive Detonating Substance.
- □ CLX 533 was qualified by the IDF as IHE with a class/division 1.5 UN (Very Insensitive Explosive Substance).

Acknowledgments

To the directorate of technologies,
Israel Ministry of Defense (IMOD)
for their assistance and the support for this research task.
To IMI explosive team: Avi, Gila, Hagay, Idit, Giora, Haiim R.

We thank you for your attention!



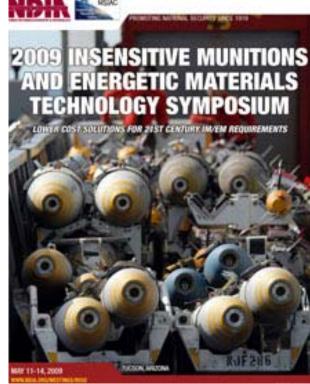
The Performance of Insensitive Blast Enhanced Explosives

Werner Arnold, Ernst Rottenkolber (*)

TDW - Gesellschaft für verteidigungstechnische Wirksysteme mbH Schrobenhausen, Germany

2009 Insensitive Munitions and Energetic Materials Technology Symposium
May 11 – 14, 2009
Loews Ventana Canyon Resort, Tucson, AZ, USA







Outline

- Motivation
- Yield of an Explosive
- Test Setup
- Test Results
- Numerical Simulations
- Conclusions



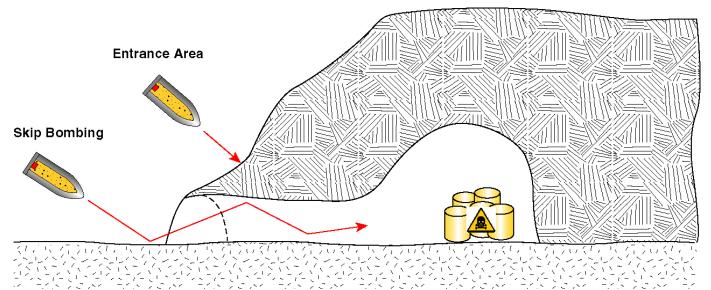
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SIBEX: Shock Insensitive Blast Enhanced High EXplosives







IMEMTS 06, Bristol, UK: "What Influences the Shock Sensitivity of High Explosives?"

IMEMTS 07, Miami, FL, USA: "SIBEX: Modelling and Testing"

Page 4 W. Arnold

SIBEX Performance



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What characterizes the Yield of an Explosive

Conventional HE

6 msec



WTD 91 - GF240

SIBEX

6 msec

30 msec





30 msec

60 msec





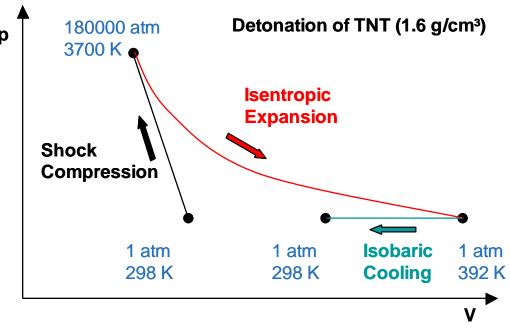
60 msec

Page 6 W. Arnold

SIBEX Performance



"Heat of Detonation" (= Energy of Detonation): TNT



Process	Energy [kJ/g]		
Shock Compression	-1.41		
Isentropic Expansion	5.94		
	4.53	4.53	Mechanical Energy of Detonation
Isobaric Cooling		0.08	Thermal Energy of Detonation
		4.61	Total Energy of Detonation



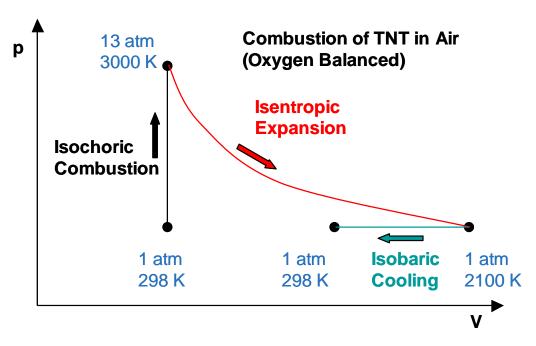
"Useful Work" Ficket & Davis "Detonation", 1979

Page 7 W. Arnold

SIBEX Performance



"Heat of Combustion" (= Energy of Combustion): TNT



Process	Energ	y [kJ/g]	
Isochoric Combustion	0.0		
Isentropic Expansion	6.4		
	6.4	6.4	Mechanical Energy of Combustion
Isobaric Cooling		8.1	Thermal Energy of Combustion
		14.5	Total Energy of Combustion



Page 8 W. Arnold

SIBEX Performance



Heat of Combustion vs Mechanical Energy (Useful Work)

Fuel	Net Heat of Combustion (calculated) [kJ/g]	Volume of Air [m³/kg]	Mechanical Energy of Combustion [kJ/g]	O ₂ -Balance [Mass-%]
В	58.7	35	23.2	-222
Fuel-Oil	46.9	15	21.2	-333
НТРВ	42.0	15	19.0	-319
DOA	33.9	13	15.3	-263
С	32.8	12	14.5	-266
Si	32.3	16	13.3	-114
Al	31.0	15	12.9	-88.9
PMMA	27.6	9	12.5	-191.8
Mg	24.7	13	10.1	-65.8
IPN	17.2	5	7.98	-99.0
TNT	14.6	4	6.72	-74.0

For Example: TNT-Equivalent of Aluminum

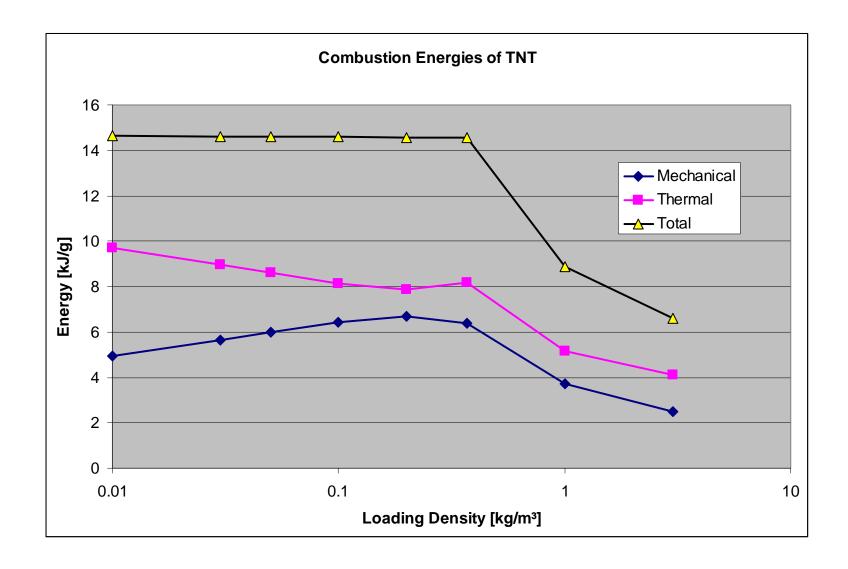
Mechanical Energy of Combustion TNT = 6.72 kJ/g vs AI = 12.9 kJ/g: TNT-Equ ~ 2

Page 9 W. Arnold

SIBEX Performance

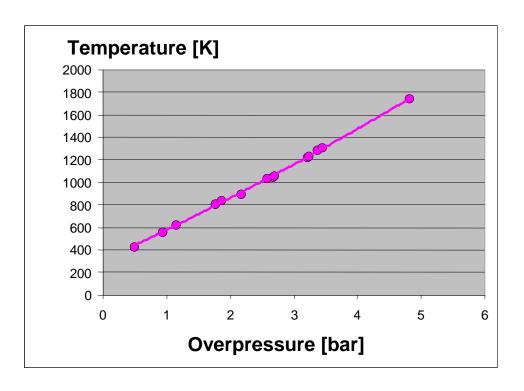


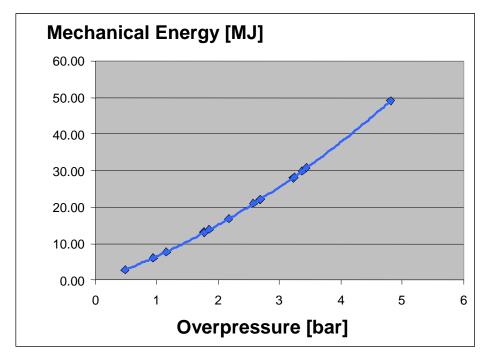
TNT: Energy of Combustion vs Loading Density





Correlation: Mechanical Energy & Equilibrium Pressure (QSP)

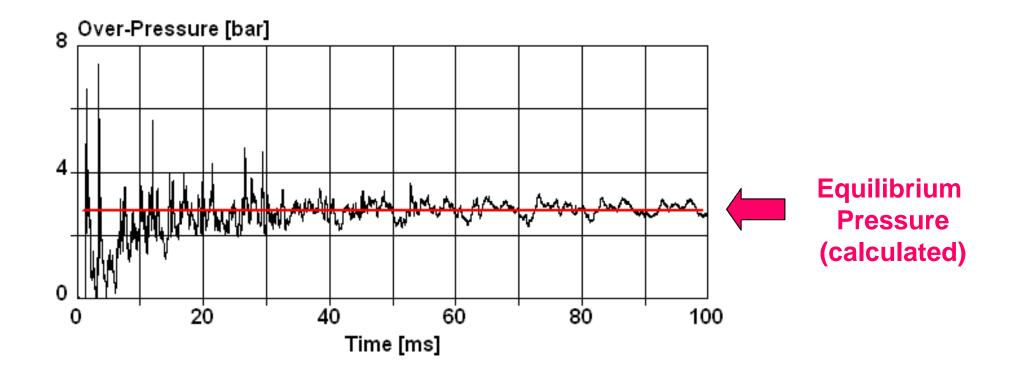




Simulations for a variety of HEs PETN highly metallized Formulations



Measurement of Quasi-Static Pressure (QSP)



- Shock Reverberations within Detonation Chamber
- Energy & Mass Losses due to Heat Transfer & Openings

QSP_{exp}(t) t = 50, 100 ms & QSP_{max}

Page 12 W. Arnold



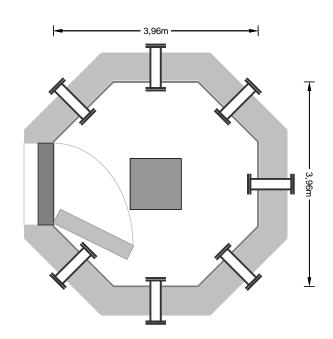
Outline

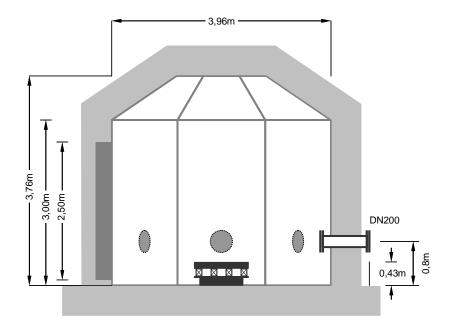
- Motivation
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ICT Test Chamber (Constant Volume)

- ICT Fraunhofer Institute, Karlsruhe, GE
 Closed detonation chamber, 45 m³, regular octagon
- SIBEX: 2 kg cylindrical shape, Dia 104 mm
- 1.50 m above ground in center of chamber
- Initiation from top
- Several pressure gauges





Page 14 W. Arnold

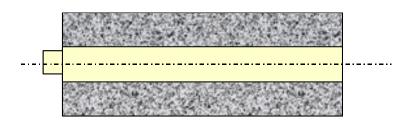
SIBEX Performance



Test Charges: Composite & SDF Charges

Designation	Components	Туре	Oxygen Balance [%]
KS22a	RDX/AI/HTPB	composite	-77
PBX-4	RDX/B/HTPB	composite	-146
BM-I	HMX/HTPB + B/DOA	SDF	-148
TB1 D	HMX/HTPB + AI/B/DOA	SDF	-116





Single body composite charge

SDF-charge (Shock Dispersed Fuel)

Page 15 W. Arnold

SIBEX Performance



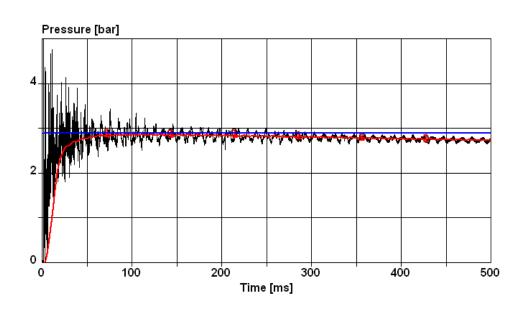
Outline

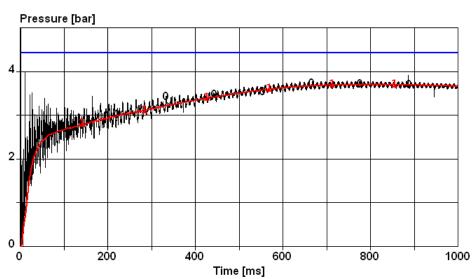
- Motivation
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Test Results: Single Body Composite Charges







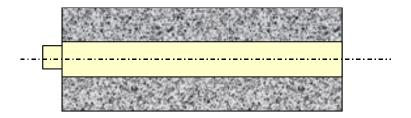
KS22a (Reference) RDX/AI/HTPB PBX-4 RDX/B/HTPB

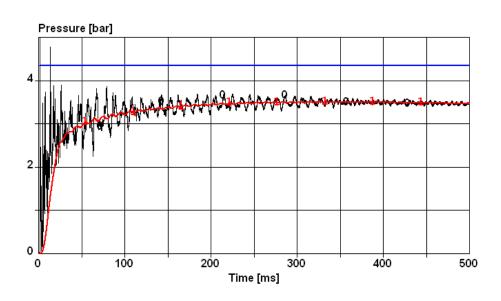
Page 17 W. Arnold

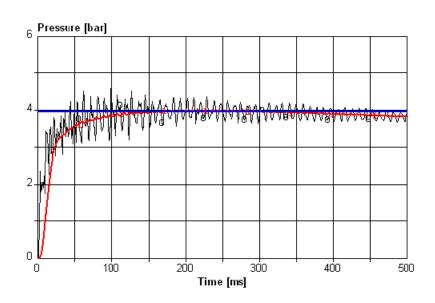
SIBEX Performance



Test Results: Shock Dispersed Fuel (SDF) Charges







BM-I HMX/HTPB + B/DOA

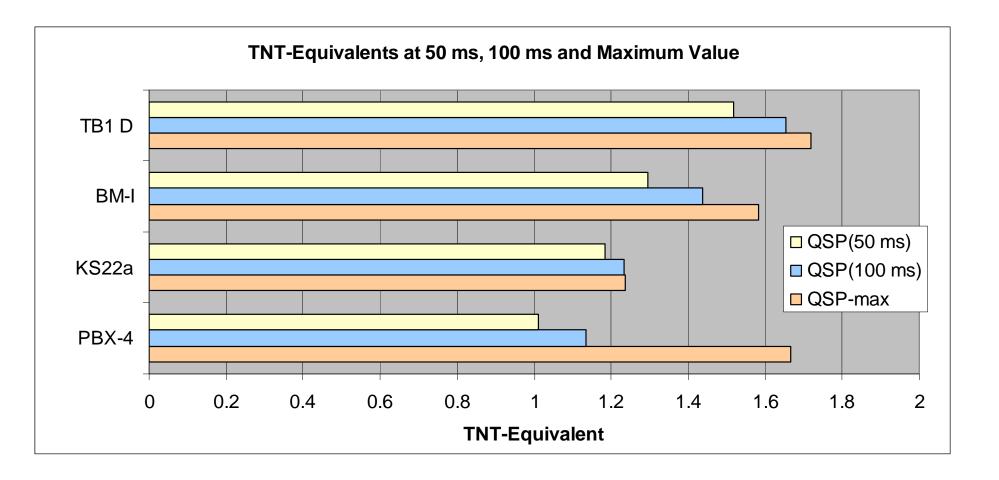
TB1 D HMX/HTPB + AI/B/DOA

Page 18 W. Arnold

SIBEX Performance



TNT-Equivalents of QSP(t)





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The Thermodynamic Model of Combustion

Turbulent Mixing Controlled Combustion

- Kuhl et al. (LLNL): 34th ICT Conference 2002
- Application: TNT & PETN (conv. CHNO-explosive)

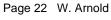
W. Arnold, E. Rottenkolber Combustion of an Aluminized Explosive in a Detonation Chamber 39th International Annual Conference of ICT June 24 – June 27, Karlsruhe, 2008

- Application: KS22a (Al-powder containing explosive)
- Modifications & extensions:



Numerical Simulation: Video Clip



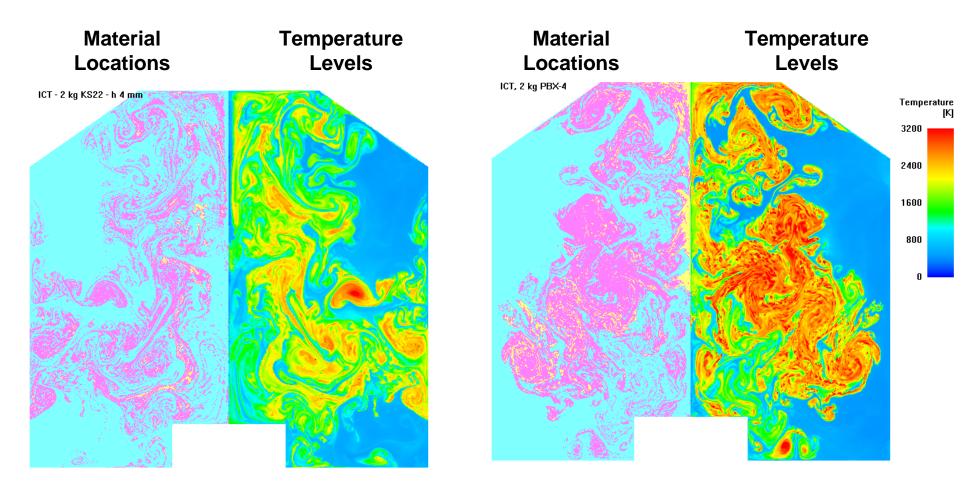


SIBEX Performance



Comparison: Material Location & Temperature KS22a vs PBX-4

t = 20 ms



KS22a -77% O₂ Deficit

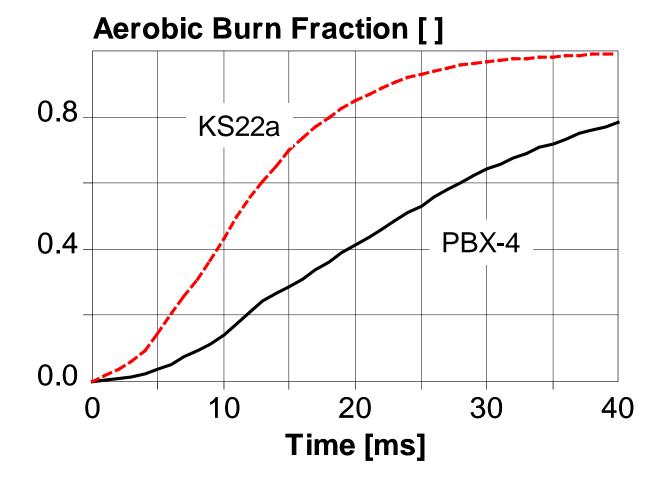
PBX-4 -146% O₂ Deficit

Page 23 W. Arnold

SIBEX Performance



Aerobic Burn Fraction: KS22a vs PBX-4





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Conclusions

- > Good correlation between mechanical energy and quasi-static pressure.
- ➤ Combustion of composite charges with an extremely high oxygen deficit is slowed down by the difficulty to mix the detonation products with air.
- > Shock dispersed fuel (SDF) charges with an equally high oxygen deficit have a higher overall burn rate compared to composite charges.
- > The best charges achieved TNT-equivalents between 1.5 and 1.7
- > Future enhancements:
 - faster reacting metal particles
 - means to accelerate mixing of fuel with air



Thank You for Your Attention!

Any Questions?

Your Contact:

Dr. Werner Arnold

Phone: +49 8252 99 6267

Email: werner.arnold@mbda-systems.de

Page 27 W. Arnold

SIBEX Performance





U.S. Army Research, Development and Engineering Command



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Insensitive Munitions and Energetic Materials Workshop Institute for Multi-Scale Reactive Modeling

> William H. Davis Ernest L. Baker David G. Pfau 11-14 May 09



Institute Formation



- ARDEC and ARL responded to HPCMO* call for HSAI** proposals
 - "An Institute to advance the computational toolset for the IM modeling community"
 - Reactive chemistry of explosives and propellants for use by the insensitive munitions modeling community (one of six technical areas)
- DA ASAALT (Dr. Parmentola) selected ARL-ARDEC proposal to go forward to DoD
- DoD HPCMO awarded IMSRM and two others on 6 Feb 08
- Develop a user-friendly, agile toolkit for rapid design tradeoffs and assessments to predict the response of munitions to threats and hazards
 - * High Performance Computing Modernization Office
 - ** High Performance Supercomputing Application Institute

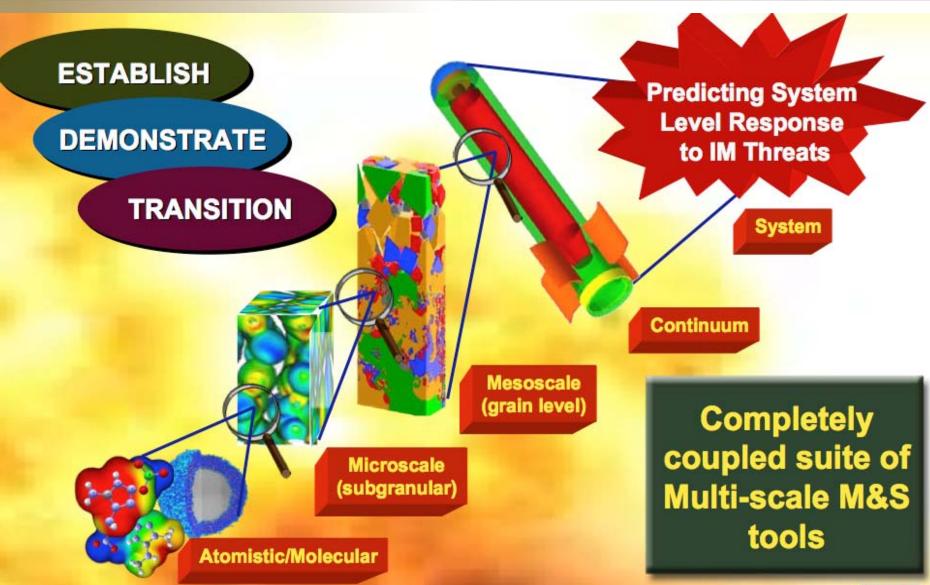




Conclusion 2



HPG





Institute Highlights (from initial briefing to HPCMO)



Statutory Requirements: IM compliant munitions

DoD Directive 5000.1; Chairman, Joint Chiefs of Staff Instruction (CJCSI) 3170.01F; and CJSC Manual (CJSCM) 3170.01B

Challenges

Overall: Coupling methods and codes for time/length scales

- 1. MD parameterization of EM
- 2. Mesoscale simulation of EM response
- 3. Homogenization methods

Institute will revolutionize M&S in munition design process

- Multiscale capability, incorporating fundamental physics/chemistry
- · Reduction of empiricism
- Faster Design and Implementation
- · Reduced risk, cost and time
- Extrapolation to novel, potentially more capable designs

Impact if HSAI not chosen

- Perpetuation of M&S tools with high levels of empiricism/inaccuracies
- Inability of extrapolate beyond existing IM threats
- Continued reliance on full-scale testing
- Increased development cost and time



Controlling the Energetic Materials
Response to Threats
Is KEY to IM Compliant Weapons

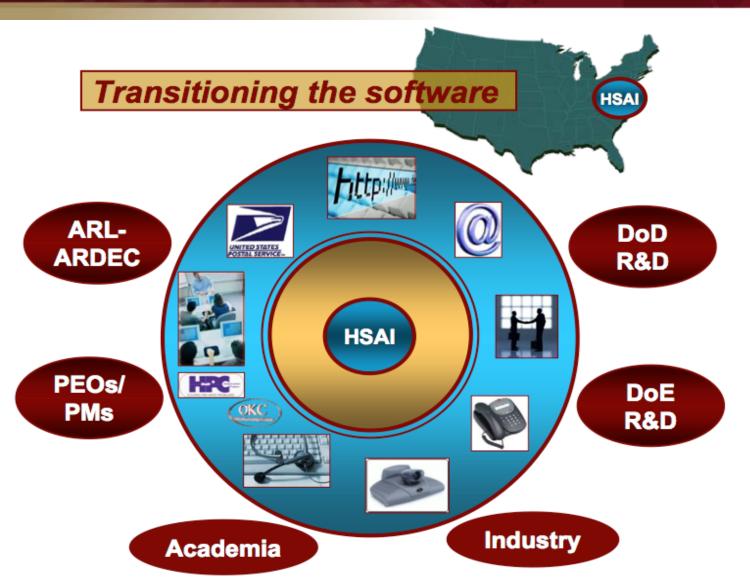






Community





HSAI web site

- Installation
- User Guides
- Release Notes
- Error reports
- Training
- Examples
- Test Suite
- Benchmarks

SW V&V

- •SW V&V Plan
- Requirements
- Design
- Integration
- Testing
- Installation
- Maintenance

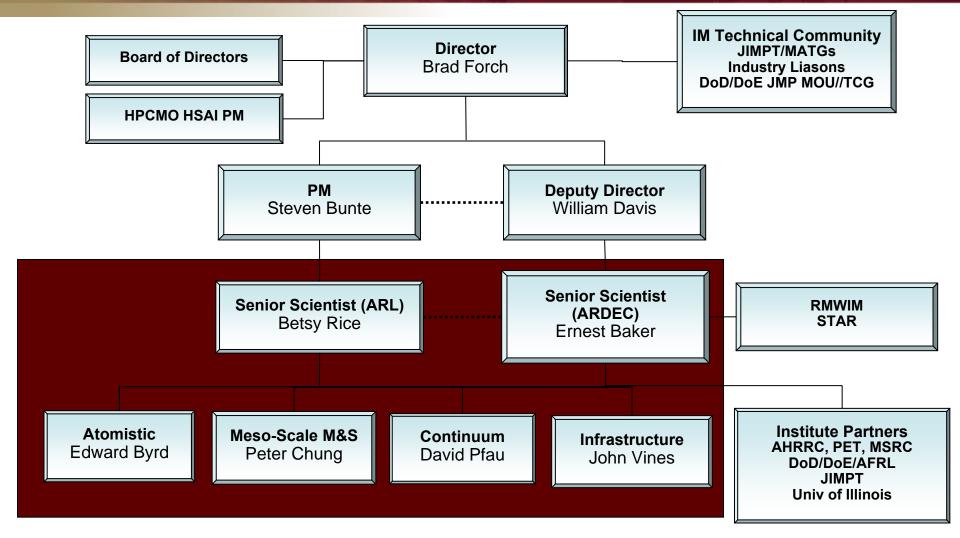






IMSRM Organization









Board of Directors



1 IMSRM BoD meeting took place 8 Jan 09 at ARL/Aberdeen BoD Approved Strategic and 09 Annual

Board of Directors

Cray Henry, HPCMO

John Parmentola, ASA(ALT)

Tony Melita, OSD

Seham Salazar, PEO Ammunition

Jill Smith, ARL

Pat Baker, ARL

Barbara Machak, ARDEC

Steve Cornelius, AMRDEC

Robert Sierakowski, AFRL

Judah Goldwasser, ONR/DARPA





IMSRM Team Breakout



Mesoscale

Peter Chung

Embedding Methods Constitutive Methods Mesoscale Methods Averaging or statistical sampling methods



Atomistic

Edward Byrd



SW Assessment Perform simulations at all scales V&V of all results

Continuum

David Pfau



Continuum codes (hydrocodes) Non-ideal IM explosives Thermal kinetics & ignition Coupled reaction fracture/damage Infrastructure

John Vines

Testing/optimizing SW Benchmarking **Establishing standards** Establish/maintain web site







Continuum Team



Reaction Coupling Lead
David Pfau

Financial Manager
Christine Frankovic

Thermochemistry
Ernie Baker
Christos Capellos
Leonard Stiel
Eric Bixon

DSD Univ of Illinois Scott Stewart John Bdzil ALE3D Analysis
David Pfau
Dan Suarez
Luis Costa
Anthony Dawson
Jack Pincay

Reactive Materials
Paul Redner
Ruslan Mudryy

DSD LLNL/LANL
Rose McCallen
Mark Short
John Walter

Mesoscale
Ernie Baker
Luis Costa
Anthony Dawson

Knowledge Manager Luis Costa

HPC Chuck Chin Dan Murphy

EWMTD

- Combined Effects Warheads Branch
- Explosives Research Branch
- Explosives Dev Branch QESA

RMWIN Coordination
Stan DeFisher

Molecular/Explosives Frank Owens

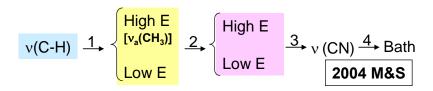


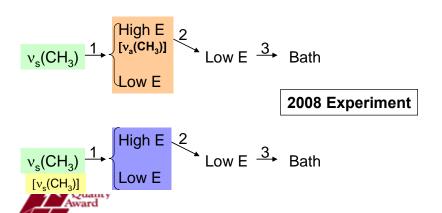
Atomistic Team



Establish methodologies to characterize energy transfer mechanisms.

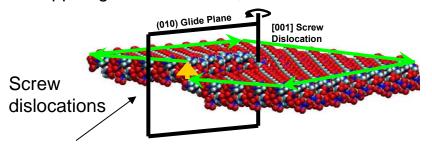
MSA: Develop methods to monitor, characterize condensed phase energy evolution for two systems (liquid NM and crystalline RDX).

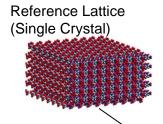




Develop a catalog of defected large/complex molecular crystals of RDX

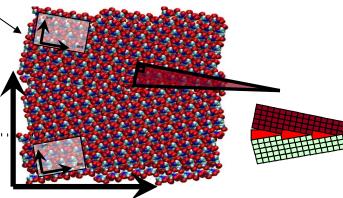
MSA: Generate models of stacking faults, twins, stepped grain boundaries, voids in RDX





Voids, interfaces, stacking faults, minimizations...

High angle grain boundaries

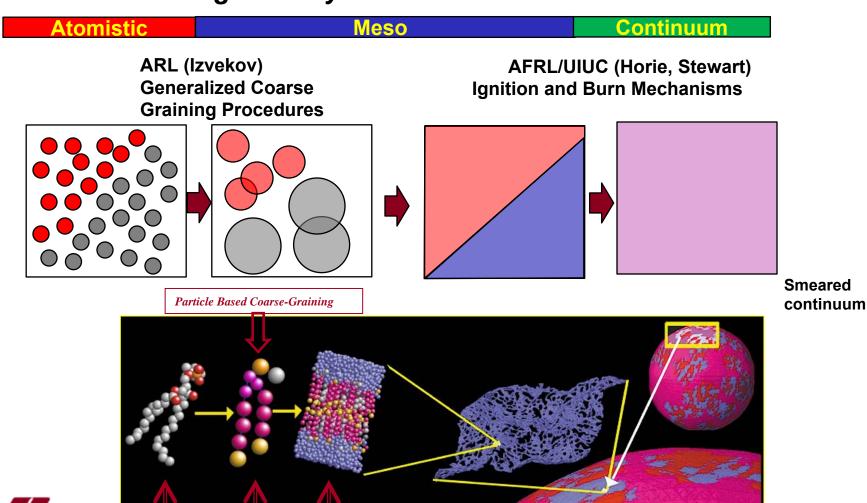




Mesoscale Team



Paving the Way for FY10 critical elements



~104 times faster than all-

atom simulation

All-atom simulations.

nm/µs

Approved for Public Release: Distribution unlimited.

Scale: Ang/ns



Non-ideal IM explosives - DSD

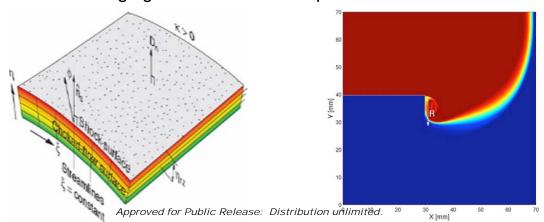


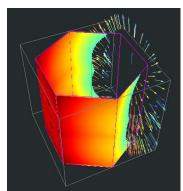
Non-ideal IM explosives

- Measure: Accurate prediction of behavior/performance of new and emerging non-ideal IM formulations such as IMX-101 and IMX-102.
- Metric: Incorporate advanced reactive chemistry with modeling of non-ideal detonation into large critical diameter item hydrocode analysis. Use advanced reactive chemistry to demonstrate improved accuracy among several and various large critical diameter items.

Annual Goals

- Institute personnel will collaborate with detonation shock dynamics (DSD) and high rate continuum hydrocode computer program developers in order to couple a new DSD computer program to a high rate continuum modeling computer program, providing a new detonation velocity modeling capability for non-ideal IM explosive formulations.
 - MSA: : Selection of Institute partners based on DSD development and high rate continuum model implementation expertise. Cooperative interfacing of DSD capability to selected high rate continuum computer program.
 - MOS: Initial DSD/hydrocode burn time capability and algorithms that represent detonation fronts of non-ideal explosives in accordance with DSD theory. Demonstrated 10% improved burn times for diverging detonation of IM explosive in FY10





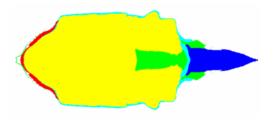


Non-ideal IM explosives - DSD **ARDEC Applications**

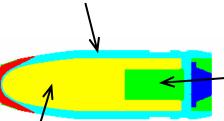


IM Advanced Smaller Munitions

Less sensitive explosives with larger critical diameters



Hardened Steel Case



Base/Nose Mounted Fuze

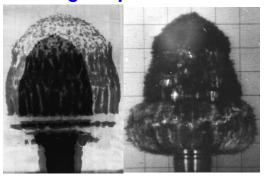


Hardened Fuze Technology

Increased Lethality Fragmentation



Combined Effects High Explosive



ALACV

Hardened Projectile for increase warhead survivability against

Urban Structures



Urban Wall Bash-through (Brick-Over-Block, Tile &/or Adobe)





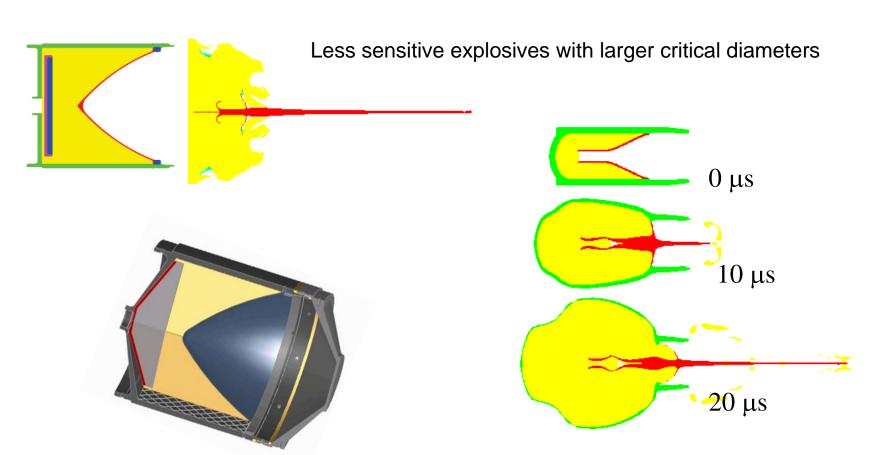




Non-ideal IM explosives - DSD ARDEC Applications



IM Shaped Charges







Continuum Team



Non-ideal IM explosives

Collaboration with detonation shock dynamics DSD and high rate continuum hydrocode computer program developers in order to couple a new DSD computer program to a high rate continuum modeling computer program, providing a new detonation velocity modeling capability for non-ideal IM explosive formulations.

Kinetics & ignition

Research in and application of thermal ignition, reaction kinetics and equation of state for aluminum. Initial work is represented in a thermochemical equilibrium code. We will work to implement a new explicit partial reaction equation of state into a hydrocode in order to develop a reaction coupling approach, giving it a more robust predictive capability for metalized IM explosives.

Coupled reaction fracture/damage

Incorporate and demonstrate the capability to perform large scale chemical reactions coupled to energetics fracture damage based on mesoscale predictive models. New energetics fracture and failure modeling capabilities are beginning to emerge based on meso/macro approaches (namely the Visco-Scram and Visco-DCA codes). We will perform either code linkage or in-code coupling of these new and emerging energetics fracture and failure models to energetics reactive flow calculations.



Thermal Chemistry & Ignition



ARDEC Development

- Development of thermochemical equilibrium model (JAGUAR)
- Formal optimization of EXP-6 potentials for H-C-N-O detonation products to available experimental data
- Implementation of analytic cylinder model and JWL/JWLB equation of state parameterization using formal non-linear optimization
- Aluminum and aluminum reaction products equation of state development and implementation
- Partial reaction equation of state development and implementation into high rate continuum modeling (CALE)

Planned ARDEC IMSRM Development

- Development of atomistic based EXP-6 potentials for H-C-N-O products for which no data exists
- Development of equations of state for non-ideal IM explosives
- Implementation of partial reaction equation of state into ALE-3D





Kinetics and Ignition



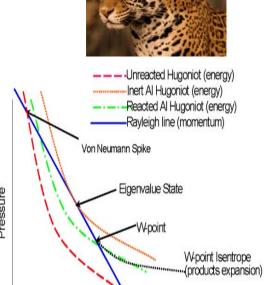
Kinetics and Ignition

- Measure: Accurate prediction of behavior/performance of new and emerging non-ideal IM formulations such as IMX-101 and IMX-102.
- Metric: Incorporate advanced reactive chemistry with modeling of non-ideal detonation into large critical diameter item hydrocode analysis. Use advanced reactive chemistry to demonstrate improved accuracy among several and various large critical diameter items.

Annual Goals

Research in and application of equation of state for aluminum. Initial work is represented in a thermochemical equilibrium code. We will work to implement a new explicit partial reaction equation of state into a hydrocode in order to develop a reaction coupling approach, giving it a more robust predictive capability for metalized IM explosives

- MSA: Development of new partial reaction equation of state parameterization routine algorithms in thermochemical equilibrium code representing aluminum, boron or silicon reactions in an IM formulation realistically. Inclusion of new partial reaction equation of state capability with metalized explosive in a hydrocode.
- MOS: Implementation of new capability and algorithms in thermochemical equilibrium code that represent partial reactions in accordance with eigenvalue detonation theory and/or other means of calculating and parameterizing partially reacted equations of state. Implementation of a new partial reaction equation of state into a hydrocode. Demonstrated agreement to cylinder test data for metalized IM explosive within 5% in FY10.



Jaguar, Cheetah

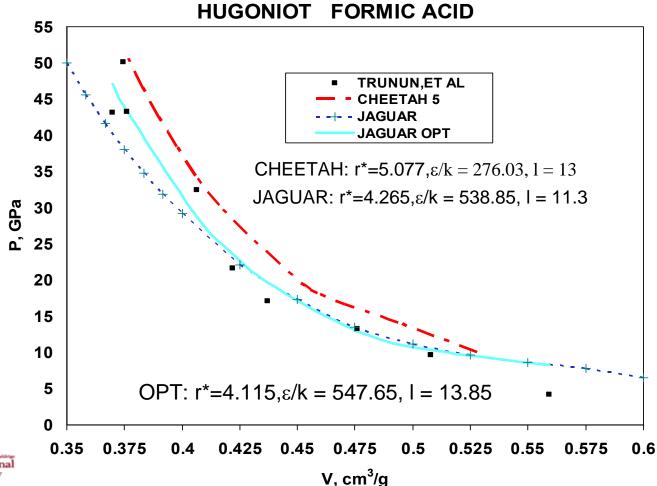
Specific Volume



Recent Progress



Experimental Hugoniot values for formic acid compared with current Cheetah and Jaguar EXP-6 parameters. New optimized parameters.



Conclusion



ESTABLISH

Predicting System

- Nominal 6 year funded program with planned POM 5 year extension
- Important collaborative effort between ARL and ARDEC in EM/IM computation
- Potential to radically alter IM development methodology
- Coordination/collaboration DoE Labs
- Well-funded synergy of size spectrum approaches to Insensitive Munition / Energetic Material development, analysis and prediction

<u> Otomistic/Molecular</u>

FIN



GENERAL DYNAMICS Ordnance and Tactical Systems

Prepared by

Nausheen Al-Shehab, Ernie Baker: US ARMY ARDEC David Hunter, Joe Morris: GD-OTS

Prepared for
NDIA Insensitive Munitions &
Energetic Materials Technology Symposium
May 11-14
Tucson, AZ



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Modeling Methodology for Predicting SCO Performance of the Excalibur Warhead

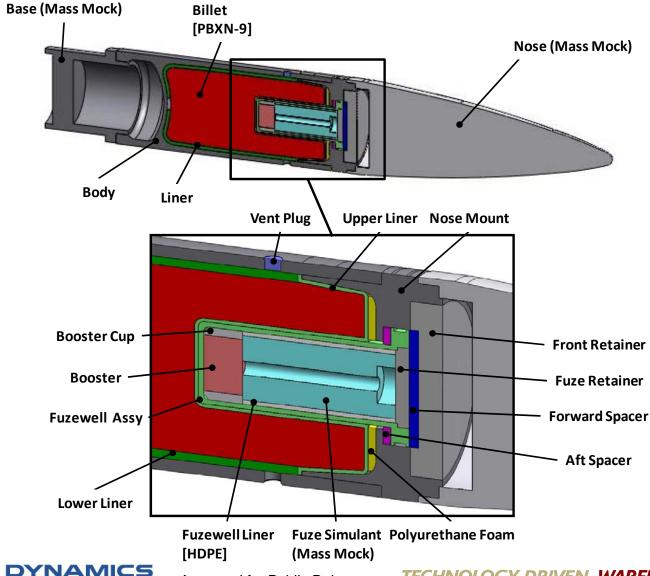


- The objective of this presentation is to describe a thermal modeling methodology used to analyze Slow Cook-Off in the Excalibur Warhead
- Modeling Goals are as follows:
 - To gain understanding of heat transfer in the Excalibur warhead when exposed to slow heating environment
 - Use this understanding to design mitigation methods that ensure the Excalibur warhead burns (Type V Reaction) during slow heating environment



Excalibur SCO Test Article







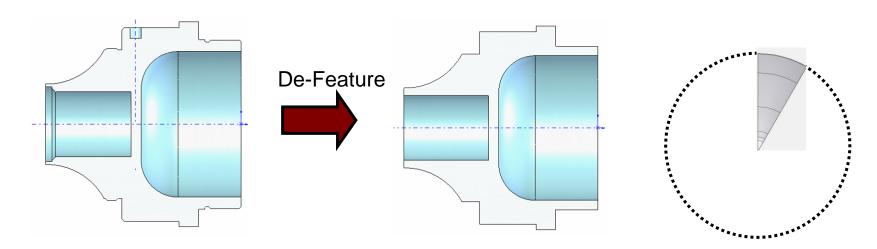
- Steps used for thermal modeling and analysis
 - De-Feature Model
 - Apply Contact Resistances
 - Define Material Properties
 - Define Thermal Loads and Constraints
 - Run Thermal Model
 - Compare Model to test results



De-Feature Solid Model



- "De-featuring" a solid model means parts are simplified or combined in an effort to reduce computational size of the model.
 - Assemblies made from the same material can be combined
 - Features such as fillets and chamfers are eliminated
 - Symmetry used where possible
 - Use "wedges" on axisymmetric parts or assemblies





Apply Contact Resistances



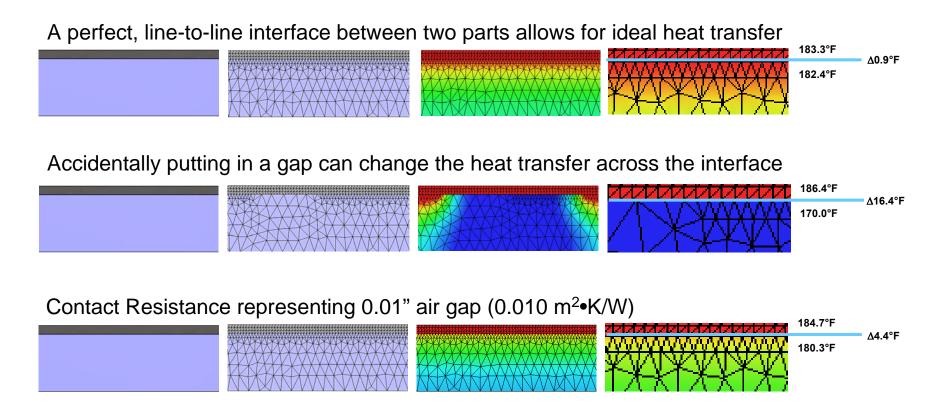
- Presence of gaps caused by tolerances can change how heat transfers across material interfaces
- Contact resistances can be applied between surfaces
 - Interfaces must be line to line
 - Resistance value calculated based on gap thickness and thermal conductivity of filler material (air, RTV, etc.)
 - Gap Thickness = t [m]
 - Thermal Conductivity = k [W/m•K]
 - Contact Resistance = t/k [K•m2/W]
 - Resistance increases as gap thickness increases
 - Resistance increases as thermal conductivity decreases



Line-To-Line Interfaces



- The three cases below illustrate how interface conditions can change thermal transfer
 - One hour calculation with convection applied to upper surface





Define Material Properties



- Material properties required for thermal model:
 - Density
 - Thermal Conductivity
 - Specific Heat
 - Kinetic Constants
 - Activation Energy
 - Pre-Exponential Factor
 - Heat of Reaction



Basic Material Properties



- Basic Material Properties are input as constants or as a function of temperature
 - Density
 - Thermal Conductivity
 - Specific Heat
- Material properties for explosive formulations are not always published so the Rule of Mixtures can be applied based on the component materials

$$k = \sum (f_i \bullet k_i) = f_1 k_1 + f_2 k + \dots + f_i k_i$$

$$f_{1} = \frac{wt\%_{1}}{\frac{\rho_{1}}{\rho_{1}} + \frac{wt\%_{2}}{\rho_{2}} + \dots + \frac{wt\%_{i}}{\rho_{i}}}, \quad f_{2} = \frac{wt\%_{2}}{\frac{\rho_{2}}{wt\%_{1}} + \frac{wt\%_{2}}{\rho_{2}} + \dots + \frac{wt\%_{i}}{\rho_{i}}}, \quad \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{etc.} \quad \text{one one of each component}}$$

 $k = thermal\ conductivity\ of\ each$ component $f = volume\ fraction\ of\ each$ component $wt\% = weight\ percentage\ of\ each$ component $o = density\ of\ each\ component$



Self Heating Properties



- An Arrhenius rate equation is used to calculate the selfheating properties of the explosive as a function of temperature
- Activation Energy, Heat of Reaction and Pre-Exponential Factor are the kinetic constants
- Activation Energy and Pre-Exponential factor must be calculated by ASTM-E 698-05, if not published
 - Standard Test Method for Arrhenius Kinetic Constants for Thermally Unstable Materials Using Differential Scanning Calorimetry and the Flynn/Wall/Ozawa Method

-E/RTHeat Rate = ρ Q Z e

 ρ = Density

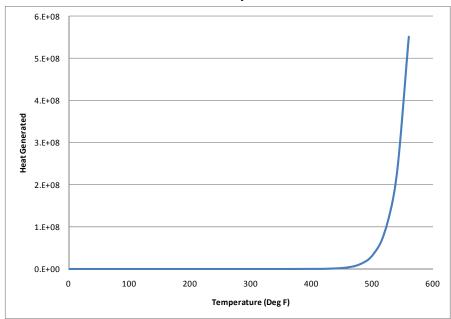
Q = Heat of Reaction

Z = *Pre-Exponential Factor*

E = Activation Energy

R = Universal Gas Constant

T = Absolute Temperature





Thermal Loads and Constraints



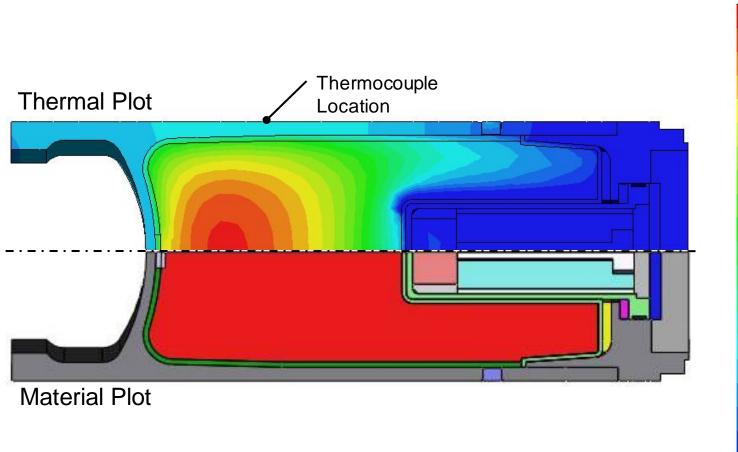
- The initial temperature of all components is the start temperature to be used during SCO tests
 - 122°F most common
- Convection is applied to all surfaces that will be exposed to moving air within the oven.
 - Convection Coefficient: 12 W/m² K
 - Bulk Temperature of convective medium heated at 50°/hour or 6°/hour, depending on test conditions intended for study
- Self heating properties of explosive applied as heat power generated as a function of temperature

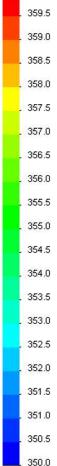


Thermal Plot at 6° F/hr Heating



360.0

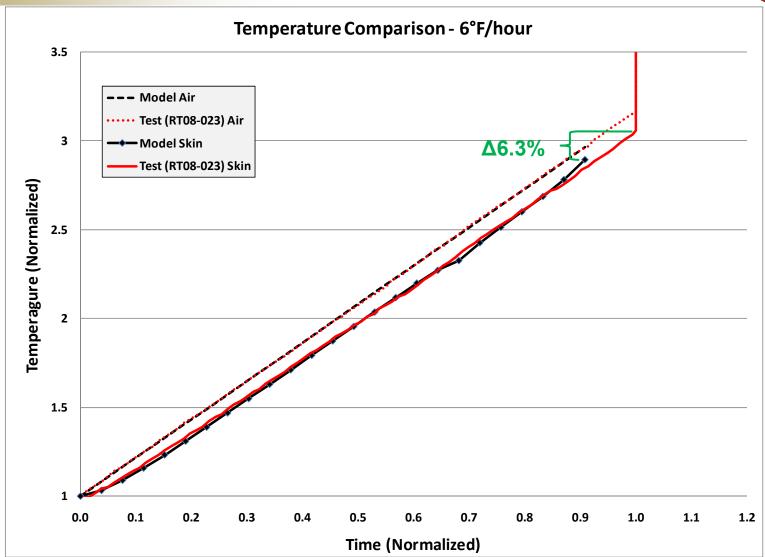






Test Data Comparison at 6°F/hr

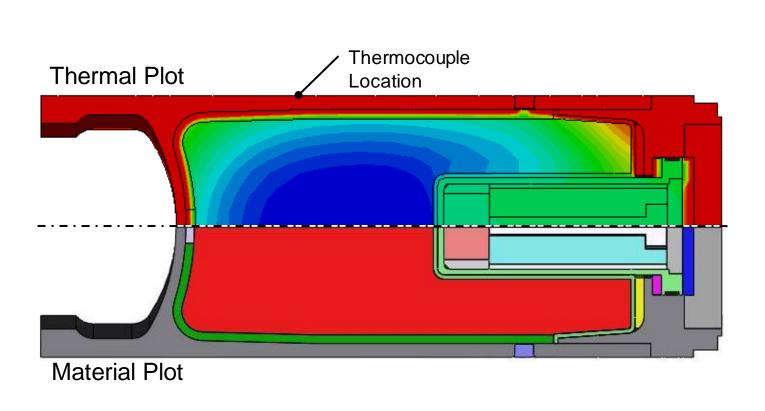


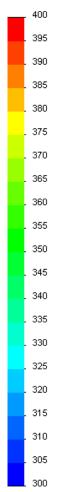




Thermal Plot at 50° F/hr Heating



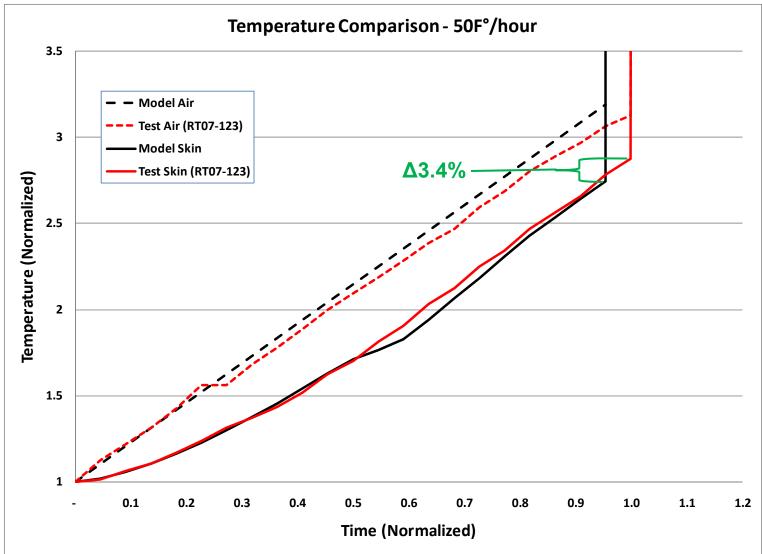






Test Data Comparison at 50°F/hr







Conclusions & Future Work



Conclusions

- A standard methodology has been developed for predicting SCO reaction times and temperatures
 - Accurate within 7% at 6°F/hour heat rate on Excalibur
 - Accurate within 4% at 50°F/hour heat rate on Excalibur
- Method can be applied to other systems

Future Work

- Continue to gather test data and compare to models
- Develop burn models to calculate what happens after reaction takes place
 - Models only predict reaction time and temperature, not Type



Acknowledgements



- Ernest Baker ARDEC
- Nausheen Al-Shehab ARDEC
- Joe Morris General Dynamics OTS
- Mike Steinberg General Dynamics OTS
- Mike Gunger Gunger Engineering















Modelling of Warhead Response to Projectile Impact with TEMPER Software





E. Lapébie (DGA/CEG)
P-F Péron (NATO/MSIAC)
F. Grannec (MSIAC Trainee)











Modelling of Warhead Response to Projectile Impact with TEMPER Software





TEMPER Software

New Modelling Improvements:

- Covered Explosive
 - NATO Fragment

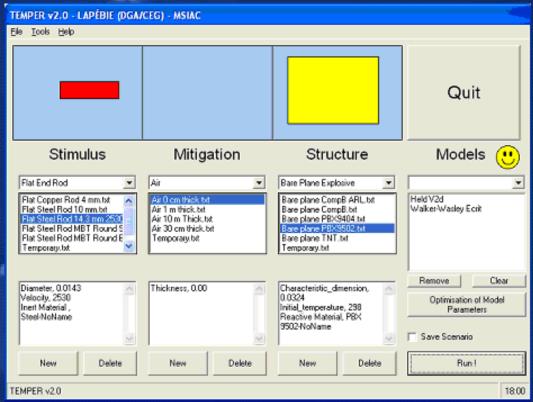
Application Example



BACKGROUND



- Toolbox of Engineering Models to Predict Explosive Descriptions
- Designed to aid in the prediction of the response of munitions to mechanical or thermal threats





FEATURES: Objects and models





STIMULI

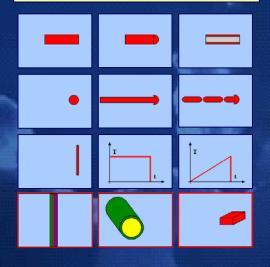
Flat end rod
Round end rod
Flat cookie-cutter
Spherical fragment
Simple shaped charge jet
Real shaped charge jet
Thin plate
Constant Temperature
Rising Temperature
Multilayer Impactor 1D
One on One Warhead
Parallelepiped Fragment

MITIGATIONS

Air Single layer Spaced plates

STRUCTURES

Bare plane explosive
Bare cylindrical explosive
Bare spherical explosive
Covered plane explosive
Multilayer Structure 1D





MODELS

V²d and u²d (Held)

E_{crit} Walker-Wasley

E_{crit} James

Y (Yactor) [modified]

V_{threshold} (Jacobs-Roslund)
t_{cook-off} (Creighton-Victor)

E_{seuil} and BSDT (Peugeot)

Godlag 1D (Baudin)







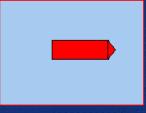






STIMULI

New projectile



New Modelling Work

- Conical-ended projectile
- Main goal:
 - Modelling the NATO fragment defined in STANAG 4496 for IM evaluations (φ 14.3 mm and 160° cone angle)



- 8 models available to model shock response
- Only one relevant for covered explosive: Jacobs-Roslund (JR)
- JR use limited by a lack of sets of parameters
- Work carried out to correlate JR parameters with explosive shock sensitivity (gap test)
- Main goal:
 - Modelling of warheads with very limited restrictions on explosive compositions

MODELS

V²d and u²d (Held)

E_{crit} Walker-Wasley

E_{crit} James

Y (Yactor) [modified]

V_{threshold} (Jacobs-Roslund)

E_{seuil} and BSDT (Peugeot)

í





- Empirical model
- Critical impact velocity for target detonation related to explosive sensitivity, fragment size and shape and cover thickness:

$$V_{\text{threshold}}(t,d) = \frac{A}{d^{0.5}}(1+B)(1+C\frac{t}{d})$$

d = fragment diameter

A = explosive sensitivity coefficient

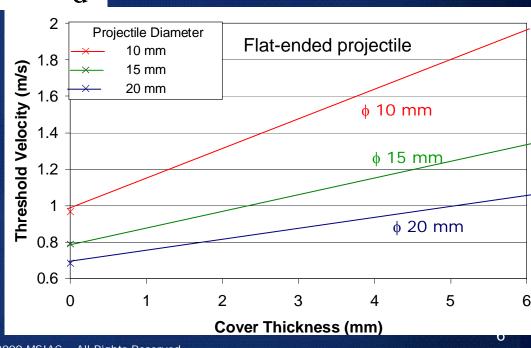
B = projectile shape coefficient

0 for flat-ended

close to 1 for round-ended

C = cover plate protection coefficient

t = warhead cover thickness

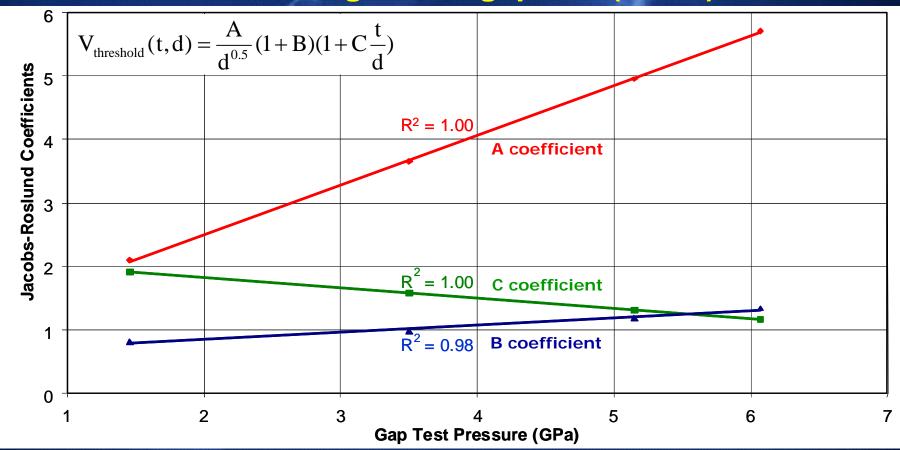








 Jacobs-Roslund parameters for various explosives have been compared to explosive shock sensitivity determined from large scale gap test (LSGT).

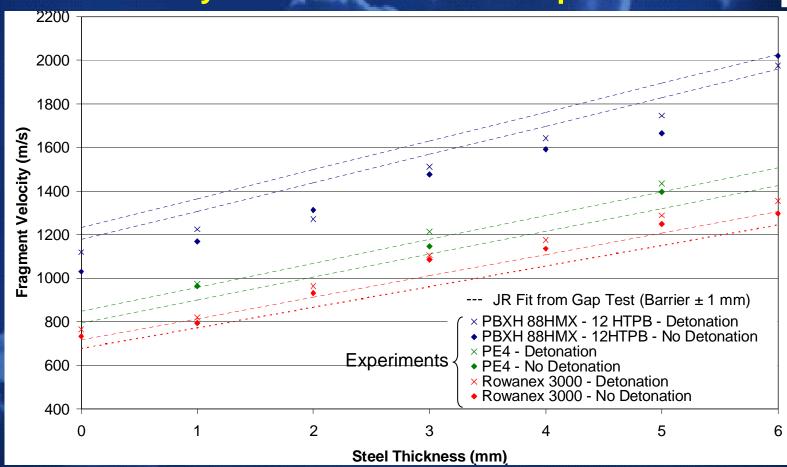








Approach validated for various explosives whose LSGT shock sensitivity was known but not JR parameters



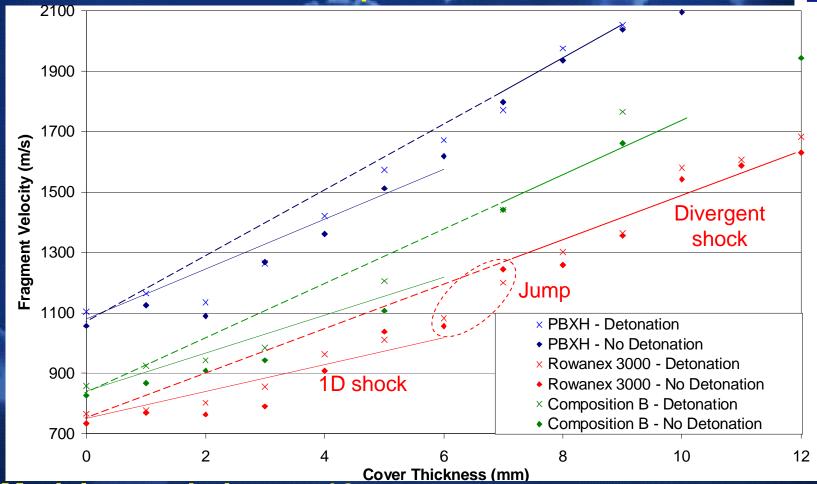
- Bare threshold slightly under- or over-estimated (± 5 to 9%)
- Curve slope well-fitted in cover thickness range [0;6 mm]







For thicker cover than 6 mm, a velocity discontinuity occurs and the curve slope increases.



- Model extended up to 10 mm
- Further validations required above 10 mm
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Extension of Jacobs-Roslund Model to Conical-Ended Fragment



- Major interest to model the NATO fragment
- Modelling based on experiments carried out by Dr Haskins with various cone angles
- Approach detailed in the paper

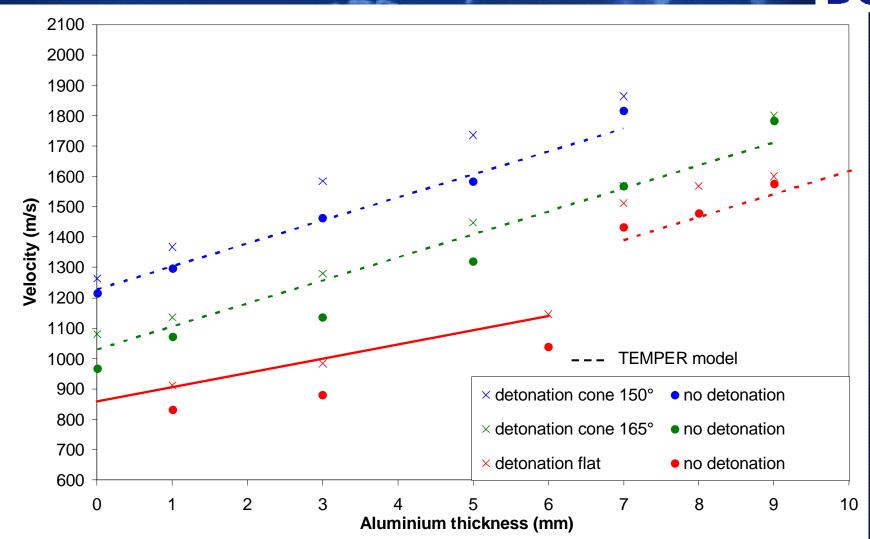


Extension of Jacobs-Roslund Model to Conical-Ended Fragment





Validation with two cone angles 165° and 150°



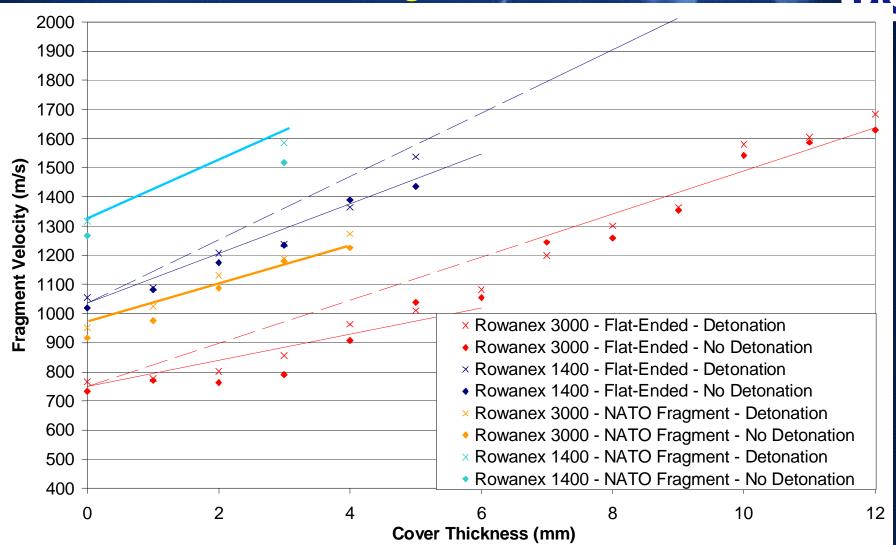


Extension of Jacobs-Roslund Model to Conical-Ended Fragment





Validation with NATO fragment







- Work presented at IMEMTS conference in 2007 about an IM improvement program for HYDRA-70 Rocket warheads
- Four explosive candidates down selected and tested against NATO fragment in a warhead mock-up
- Warhead mock-up with a steel case
 - \$\phi\$ 76 mm and 5.1 mm thick

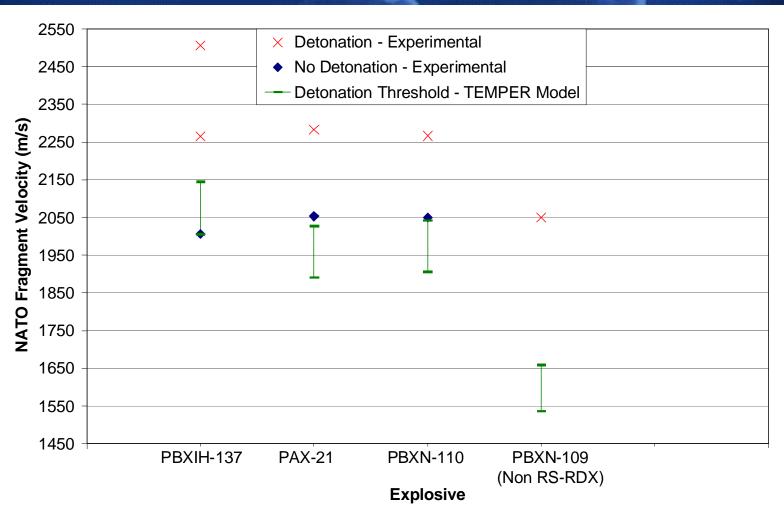
Explosive	Composition	NOL-LSGT Gap Test Threshold (GPa)
PBXIH-137	82% RDX - 18% Binder	4
PAX-21	34% DNAN - 30% AP - 36% RDX	3.62
PBXN-110	88% HMX - 12% HTPB	3.67
PBXN-109 (Non RS-RDX)	64% RDX - 20% Aluminium - 16% HTPB	2.2







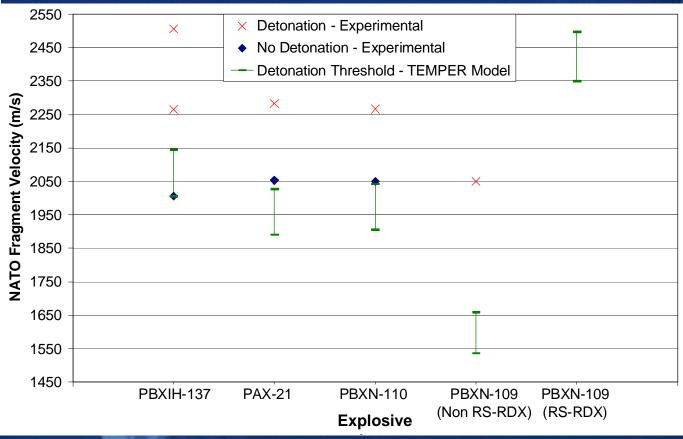
- Tests carried out at three impact velocities:
 - 2050, 2250 and 2500 m/s











- Calculated threshold velocities slightly below experimental results but very good estimation as it is only based on LSGT shock sensitivity
- Benefit of PBXN-109 with reduced sensitivity RDX other conventional RDX



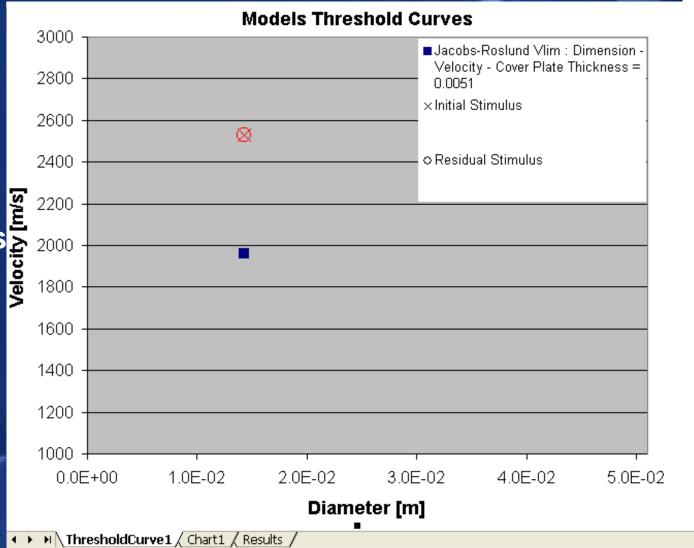




Main window

Parameters window

Results window





Conclusions



New features available in next TEMPER version

- Reasonable agreement obtained with existing experimental results
 - Validation going on
- A training session will be organized on Thursday afternoon and you can join





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Pierre-François Péron
NATO/MSIAC
p-f.peron@dga.defense.gouv.fr



Design for Insensitive Munitions Compliance of XM1069 120mm Multipurpose Tank Round



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

D.G. Pfau, S.E. DeFisher, D.A. Suarez, E.P. Scheper, E.L. Baker RDECOM-ARDEC Picatinny Arsenal, NJ



Outline



- XM1069 Intro
- Fragment Impact
 - Modeling
 - Test
- Cookoff venting
 - Penetration modeling
 - Cookoff testing



XM1069



- 120mm, Fin-Stabilized
 Multimode Tank Round
- Filled with ~5lbs PAX-3
 - HMX, Aluminum, Binder
- Computationally optimized
 - Outstanding performance against urban targets, light armor and personnel



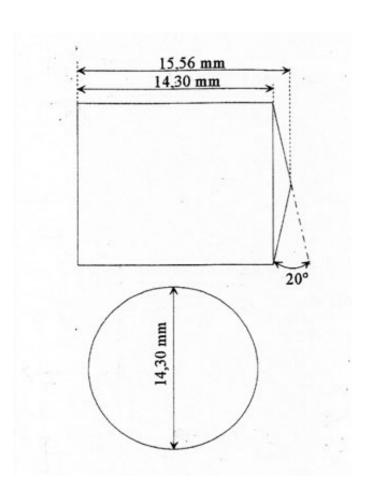




Fragment Impact



- Standardized IM test (STANAG 4496)
- 8300 ft/s (formerly 6000 ft/s) mild steel fragment
 - Shot in tactical configuration, shot in logistical configuration
- Possible shock initiation, shear or cookoff
- Required: Type V/Burn

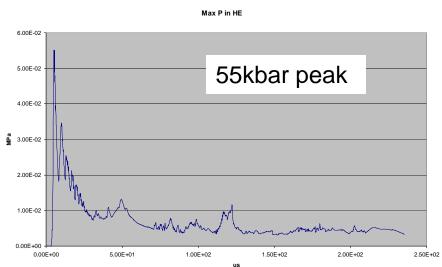


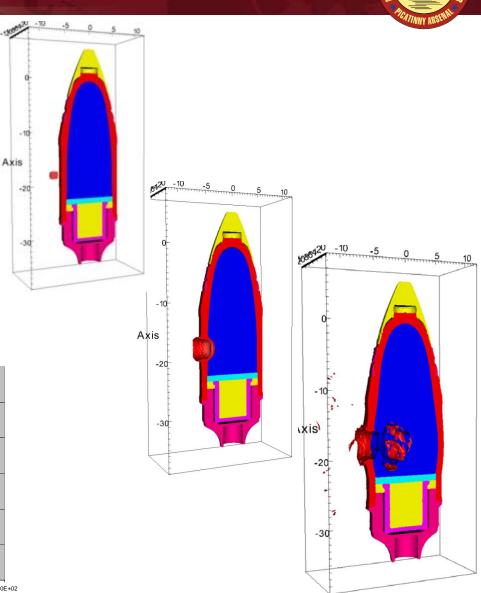


Non Explosive Main Fill



- First approach, tried-and-true
- 4M elements
- Approx 1200 cpu-hours on ARL HPCC
 - 3 calendar days on 32 cores –
 Ended by time limit
- HE main fill modeled as a Mie-Grüneisen EOS with no strength model

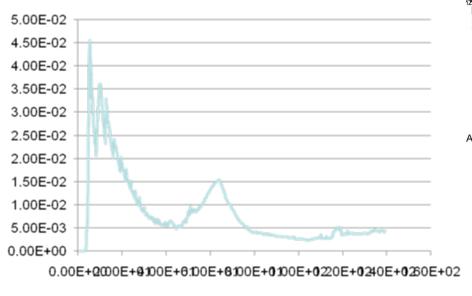


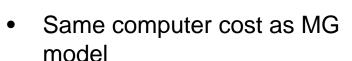




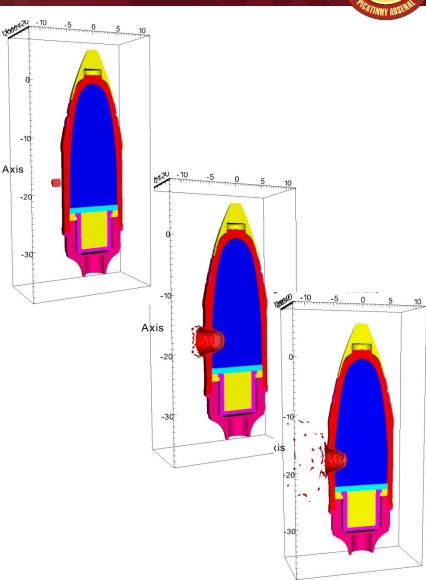
Plastic







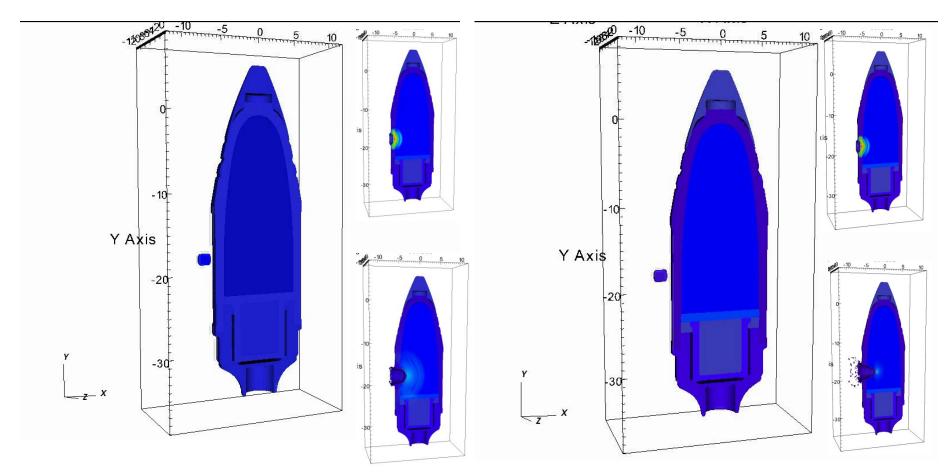
- Used PMMA or other plastic material with constitutive model
- Pressure peak at 45 kbar
- Added strength model makes penetration much more shallow





Animations





Inert Explosive Mie-Grüneisen No constitutive model

Inert Explosive Mie-Grüneisen Constant yield and shear modulus

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

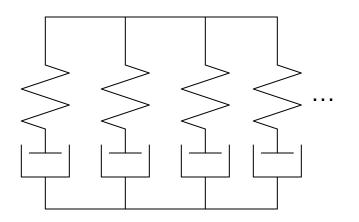


Visco-SCRAM, Visco-DCA



SCRAM

- Material is characterized by a number of springs and dashpots with statistical cracks
- Older version has thermal effects in cracks, new version does not
- Initially we only have PBX9501



DCA

- Also visco-elastic form of material
- Used for brittle HEs
- Behavior determined by "dominant crack," not an average
- No thermal term, yet
- Initially we only have PBX9501

n Maxwell elements (Visco)

plus Statistical CRAck Mechanics (SCRAM)

-or-

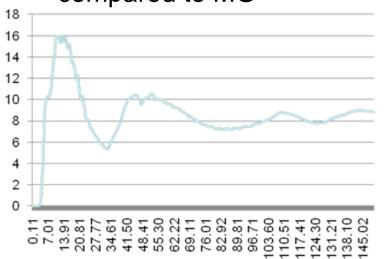
Dominant Crack Analysis (DCA)

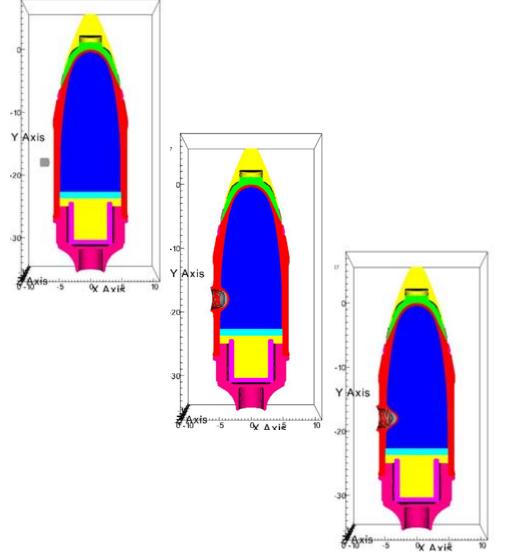


Visco-SCRAM v1



- Pressure peak is very low ~16kbar
- Fragment doesn't penetrate and even rebounds at the end
- Pressure trace shows damped oscillation
- Takes a very long time to run compared to MG



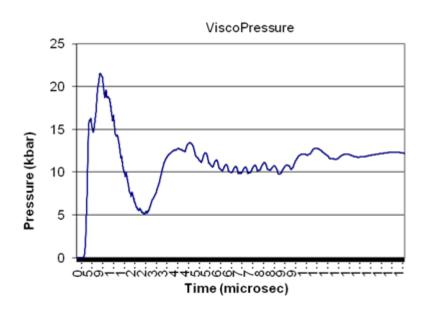


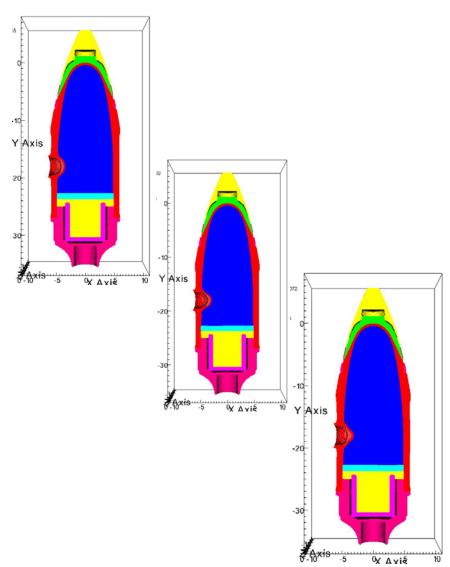


Visco-SCRAM v2



- Very similar to v1
 - Only crack mechanics updated
 - Hotspot model not included
- Pressure peak is higher than v1, lower than plastic



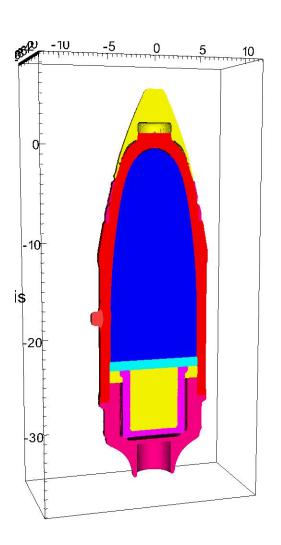




Visco-DCA



- Similar to Visco-SCRAM
- Differences would likely be in the damage morphology in the billet
- Much higher cost than SCRAM
 - Several days on 100+ processors

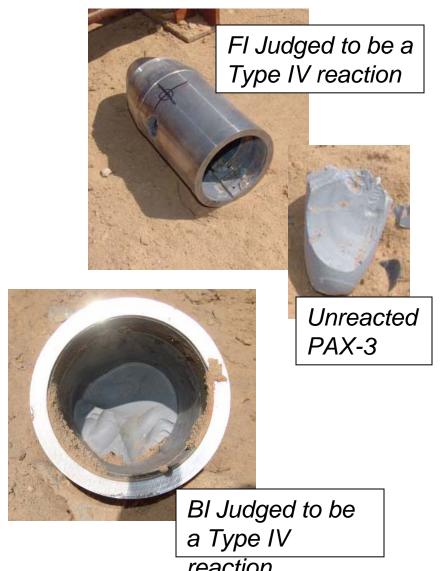




Experimental Results



- 5728 ft/s FI test conducted by General Dynamics
 - Type IV due to pressure and dent in witness plate
 - M&S Predicted 24kbar
- 2759 ft/s BI test
 - Type IV due to pressure and flight of closure disc





Future Work



- Fragment Impact will be modeled and tested with a RM PIMS liner
- Liner creates a
 hugioniot mismatch
 which reduces
 transmitted
 pressure

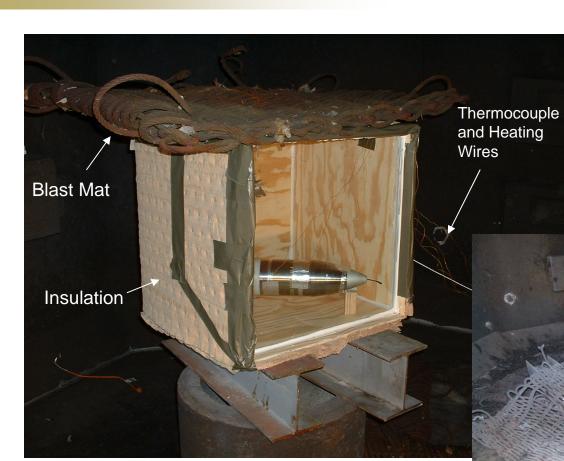






Baseline Cookoff





Type III (unofficial)

Baseline testing 50F/hr

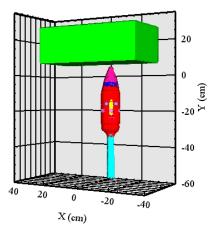
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



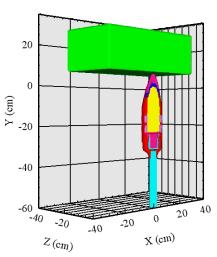
Cookoff Features



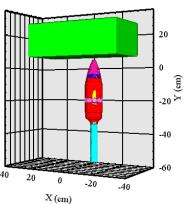
- Vent holes are needed to exhaust gasses during cook-off
- Vent hole size needed according to STEX testing: 12 holes x Ø0.58"
- Modeling performed to see the effect of vent holes on performance



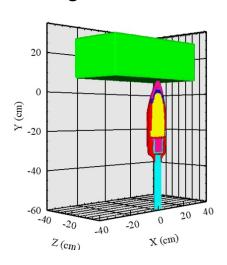
Offset holes



Aligned slots



Aligned holes



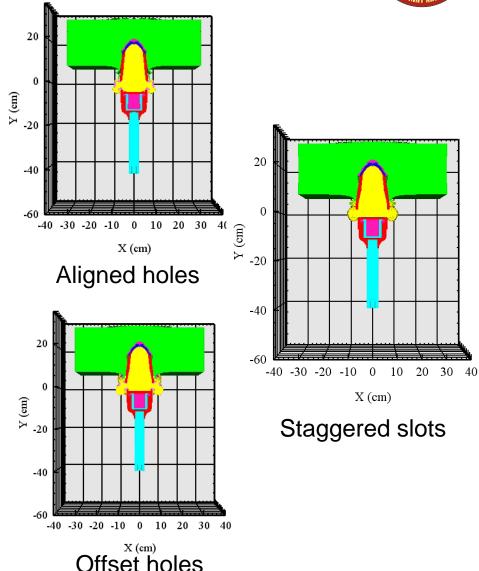
Staggered slots



Concrete Penetration



- All of the designs meeting the required vent area failed to penetrate
 - IM vents weakened
 the wall enough
 that the body
 collapsed

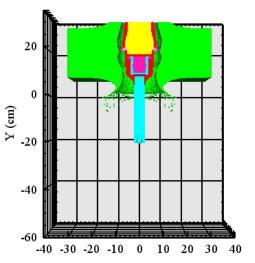




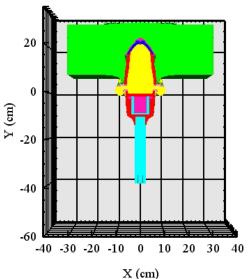
Concrete Penetration



- Design chosen: compromise vent hole size
 - Ø0.30 holes found to penetrate
 - Ø0.45 holes did not penetrate but made it ~2/3 through the wall
 - Ø0.58 did not penetrate



Ø0.30: Clears the target wall intact



ø0.45



Upcoming Work



- Vented design to be tested at ARDEC
- PIMS-lined warhead to be tested







Characterization of Existing Stockpile and Development of Synthetic CaSi₂

Dr. Paul E. Anderson
Energetics and Warheads Division,
Explosives Research and Development
Picatinny Arsenal, NJ 07806



Team Members



Cerametec, Inc.

Dr. Raymond Cutler (Program Management, powder classification), Joe Hartvigsen (XRD).

Irvin Industries

Dr. Mark Hash (synthesis)

Crane Naval Warfare Center, Test Services Branch
David Southern, Dr. Doug Papenmeier, Louis Schwenk (ICP Analysis)

Picatinny Arsenal

Kerry Henry (PM Joint Services) and Jim Terhune (PM-MAS) Dr. Ed Hochberg (AA Analysis); Henry Grau (thermal analysis, heat capacity); Deepak Kapoor, Darold Martin (XRD); Dr. Chris Haines (XRF); Gary Chen, Chris Fish, Jessica Martin (particle size analysis, SEM/EDX, thermal analysis)



Background



- Calcium Disilicide (CaSi₂) is a bimetallic compound used as an additive in many pyrotechnics and primary explosive compositions.
- Single point failure status due to dwindling stockpiles and non-specification material
- Commercial stockpiles of CaSi₂ vary in characteristics, and availability between lots and vendors. Thus, it was proposed to synthesize CaSi₂.
- MIL-C-324C contains outdated, tedious procedures for elemental composition. Newer techniques are needed to supplement current standard.
- To guide synthesis efforts, a thorough characterization of existing materials was undertaken.



Goal

Synthesize an economically feasible CaSi₂ product that is a drop-in replacement for existing product from coking process.

Objective

Eliminate single point failure of dwindling stockpile of CaSi₂ and variability between lots. Design and deliver 15 lbs of synthetic product for testing in M52A1 primer.

Tasks

Characterize existing CaSi₂ materials Formulate DOE for synthetic material and identify commercial synthetic options.

Perform synthesis runs ship to ARDEC and contractor for testing.

Test, validate
DOE model,
document, update
MIL-C-324C

Challenges

Relatively unknown chemistry and physics of CaSi₂ in primers

Need for scalable, robust technique for powder synthesis.

Approach

Identify key attributes of existing CaSi₂

Perform small scale tests for screening attributes

Item scale tests for performance testing

Use statistical DOE to identify and track attributes



Characterization Tools



- Not performed Underway Complete P Picatinny C Crane Ce Ceramatec
 - * Required for MILC-324C qualification

1	THERMAL ANALYSIS (melting point, decomposition, phase changes)
a.	Thermogravimetric Analysis (TGA): moisture content, impurities (P)
b.	Differential Thermal Analysis (DTA): phase transformations, impurities (P)
2	SURFACE MORPHOLOGY (flowability, processing)
a.	Scanning Electron Microscopy (SEM): particle morphology and size (P)
b.	Surface Area Analysis: surface roughness and porosity (P, Ce)
3	CHEMICAL/STRUCTURAL ANALYSIS (composition, crystal structure)*
a.	Energy Dispersive Spectroscopy (EDS): surface composition
b.	X-Ray Diffraction Analysis (XRD): identify and quantify compounds and impurities (P, Ce)
C.	Inductively Coupled Plasma-Atomic Absorption (ICP-AA): atomic composition (P, C) TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Characterization Tools

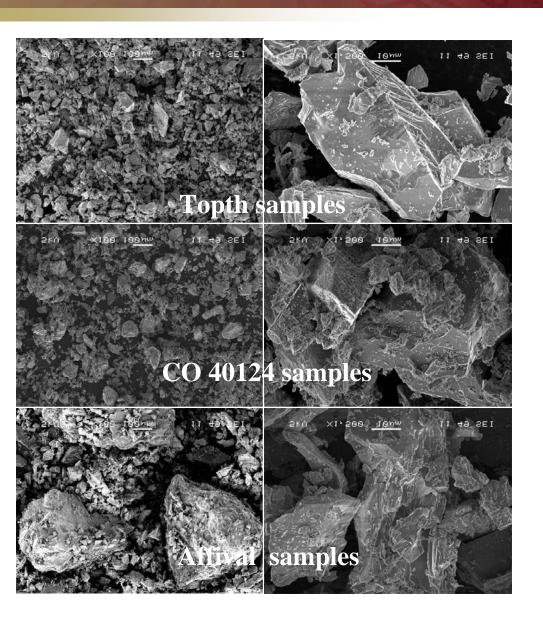


3.	CHEMICAL/STRUCTURAL ANALYSIS cont'd*
d.	X-ray Fluorescence: percent atomic species (P)
4.	MATERIAL CHARCTERISTICS (MILSPEC, particle size, density)
a.	Particle Size Analysis (PSA) (P)
b.	Tapped Density (P)
C.	Apparent Density (P)*
d.	Sieve Analysis (P)*
5.	THERMAL CHARCTERISTICS (heat flow, heat capacity)
a.	Thermal conductivity, effusivity, heat capacity (P)



Example: SEM Results





Current commercial samples: Differences in morphology will affect flowability, packing density, and sieve results.



Elemental Composition Results



Description	Si (theo)	Si(XRF)	Si(ICP) ± 1.6%	Ca (theo)	Ca(XRF)	Ca (ICP) ± 2.6%	Fe (theo)	Fe (XRF)	Fe (ICP) ± 1.8%
Run 1	58.4	58.23	58.6	41.6	40.42	39.7	0.00	0.36	0.10
Run 2	64.3	64.79	64.9	35.7	34.21	34.3	0.00	0.32	0.20
Run 3	62.4	63.85	62.9	34.6	32.56	33.1	3.00	2.87	2.90
Run 4	60.5	56.72	59.3	33.5	35.78	31.6	6.00	6.71	6.00
Run 5	61.4	59.93	59.6	34.4	35.85	30.2	2.56	3.14	2.70
Run 3R	62.4	60.84	57.6	34.6	35.11	30.8	3.00	3.37	3.20
Affival		58.6	55.9		34.4	26.2		5.58	4.80
CO 40214 - production lot	, 59.8	59.8	58.1	, 29.6	33.3	26.6	, 2.95	4.77	4.20
Topth 1205		59.1	56.7		32.7	23.6		5.45	4.80
Topth 1129		58.9	55.2		33.4	24		5.1	4.70
Perkins -7		58.6	53.8		36.6	26.1	_	3.79	3.20
Perkins -140		59.4	55.1		34.7	24.3	_	3.54	3.50

- X-ray Fluorescence and ICP analysis
- Procedure developed and carried out by Crane Naval Warfare Center
- Within error, samples of interest still fall within elemental specifications of MIL-C-324C.
- ICP recommended as technique to augment MIL-C-324C



Calculated % weight components from XRF data



Sample	% weight Si	% weight CaSi ₂	% weight FeSi ₂
MIL-324C ¹	14.1	72.1	7.6
Affival	4.8	82.6	11.2
P CO40124	8.3	80.0	9.6
Topth 1205	7.8	78.5	10.9
Topth 1129	6.9	80.2	10.2
Alfa Aesar	6.8	80.5	10.1
Perkins R 7	3.5	87.9	7.6
Perkins R 140	7.2	83.3	7.1

Assumes calcium then iron reaction only with silicon.

¹ Calculated from MIL-C-324C minimum requirements for type II (60 Si /30 Ca/3.8 Fe)



Synthetic Routes of CaSi2



Route 1. CaO + C + Si
$$\rightarrow$$
 CaSi₂ + CO

Route 2.
$$SiO_2 + 2C \rightarrow Si + 2CO$$

Fe + Si \rightarrow FeSi alloys
 $CaCO_3 + 4C \rightarrow CaC_2 + 3CO$

~1000°C

or

$$CaCO_3 + \Delta H \rightarrow CaO + CO_2$$

 $CaO + 3C \rightarrow CaC_2 + CO$

$$2SiO_2 + CaC_2 + 2C \rightarrow CaSi_2 + 4CO$$

Route 3. 2 Si (I) + Ca (I)
$$\rightarrow$$
 CaSi₂

Which route would you choose?



Sample Runs and Design Logic



Irvin Industries

6 sample runs

Ceramatec

Milling

Particle size classification/blending

- 1. Stoichiometric
- 2. Eutectic (free Si)
- 3. Eutectic + 3% Fe
- 3R. Repeat Run 3
- 4. Eutectic + 6% Fe
- 5. Blend commercial CaSi₂ + new Ca/Si

Constraints from MIL-C-324C, desire to understand effects of chemistry on performance (Fe content, CaSi ratio, free silicon)

Portion of original sample was milled in SS media in SS vessel in hexanes. Products were air passivated.

Milled samples were blended with original samples to make three products: low surface area (LSA), medium surface area (MSA), and high surface area (HSA).

Surface area, density (true, apparent, tap), heat capacity/effusivity

At least one product MIL compliant, others at extremes



Particle Size Classification and Surface Area



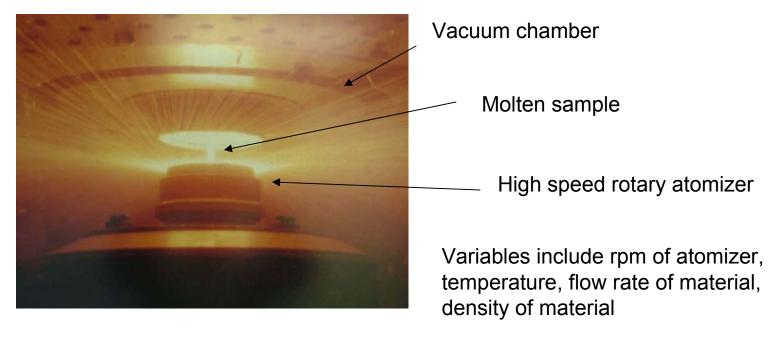
Atomizer Run	Surface area, m2/g	Batch surface area notation	Type II compliant?	
	0.117	LSA	PASS	
1	0.681	MSA	PASS	
	1.112	HSA	FAIL	
	0.148	LSA	PASS	
2	0.723	MSA	PASS	
	1.28	HSA	FAIL	
	0.127	LSA	PASS	
3	0.713	MSA	PASS	
	1.215	HSA	FAIL	
	0.106	LSA	PASS	
4	0.618	MSA	PASS	
	1.028	HSA	FAIL	
	0.122	LSA	PASS	
5	0.723	MSA	PASS	
	1.159	HSA	FAIL	
	0.131	LSA	PASS	
3R	0.703	MSA	PASS	
	1.096	HSA	FAIL	

Type II powders successfully obtained. Surface area effectively controlled at values <0.8m²/g by reblending powders.



Synthesis Effort





- Led by Raymond Cutler (Ceramatec, Inc.)
- Synthesis on Rotary Atomizer at Irvin Industries, Inc.
- Production quantities up to 45 kgs per run to 200 kgs per run (production).



Loaded Induction Furnace







Induction Furnace & Tundish

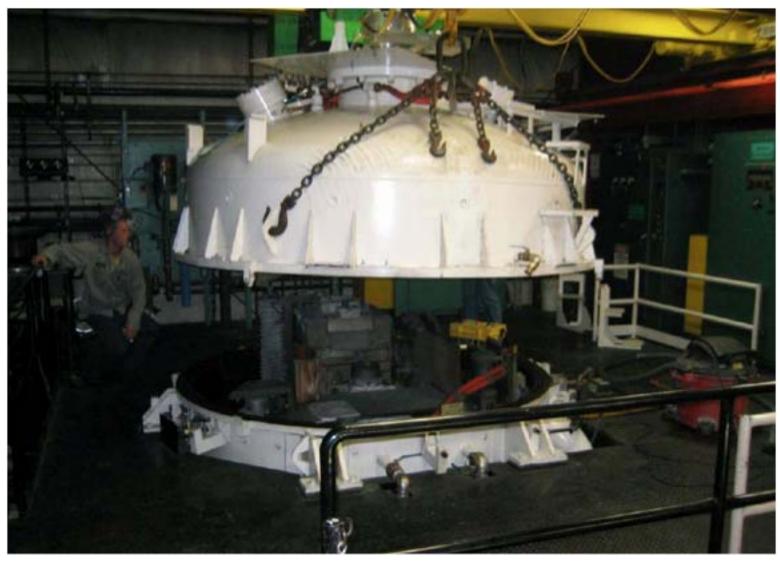






RDECOM Placing Vessel Lid





Ceramatec, Presentation at Salt Lake City



Ready For Atomization







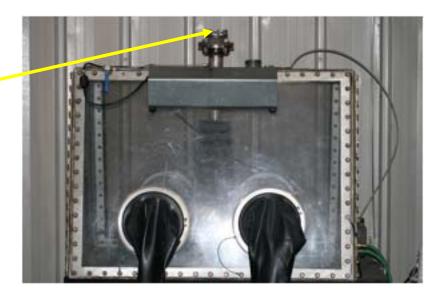
Post-Run Powder Collection and Handling



Base of atomization chamber



Powders are transferred directly to purged glove box atmosphere for sampling, screening, and packaging



Powder collection canister with mating valve to rig and glove box





Run#	Amount	Amount	nount Ervin Yield Ceramatec Yield/Overall Yield (
	Melted (kg)	Shipped (kg)	<u>%</u>	Type II LSA	Type II MS	A Type I HSA	
1	22.7	7.3	32	43/14	100/32	99/32	
2	22.7	17.7	78	64/50	100/78	100/78	
3	22.7	18.2	80	58/47	100/80	100/80	
3R	22.7	19.5	86	52/45	100/86	100/86	
4	22.7	15.5	67	14/10	41/28	99/67	
5	22.7	17.7	78	67/52	100/78	100/78	



18 Samples for Phase I



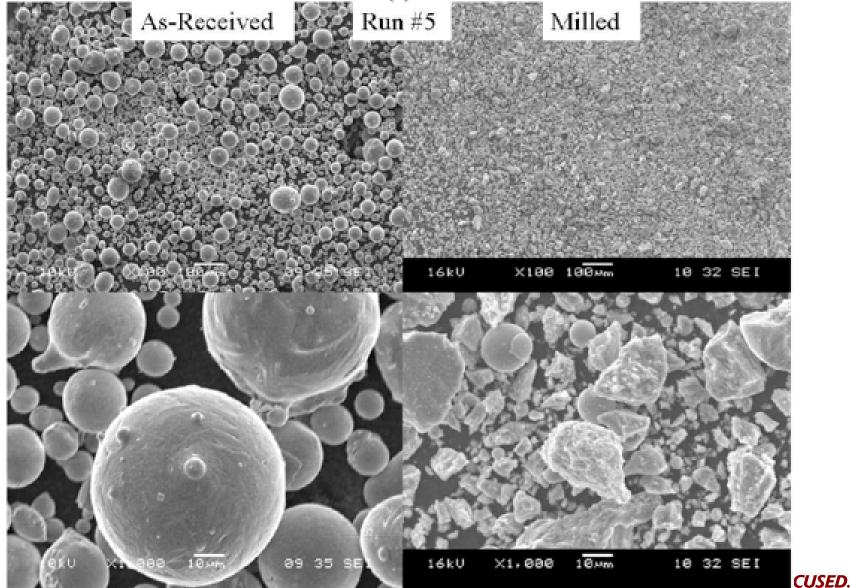
Run Surface Area (m ² /g)			Partic	le Size (μm)	
Type II Low Surface Area (LSA)	$\underline{\mathbf{d}}_{10}$	<u>d</u> 50	<u>d</u> 90	Mean	$\underline{\text{Min}}$	Max
1 (RC15-125A) 0.1168±0.0009	2.2	15.0	56.8	23.1	≈0.05	≈ 100
2 (RC15-125C) 0.1483±0.0015	3.4	15.6	51.4	21.3	≈0.05	≈100
3 (RC15-125E) 0.1271±0.0008	4.0	18.4	73.8	33.3	≈0.05	≈310
3R (RC15-126E) 0.1305±0.0009	4.9	20.4	66.7	28.8	≈0.05	≈ 110
4 (RC15-126A) 0.1063±0.0006	4.3	20.0	71.8	33.5	≈0.05	≈310
5 (RC15-126C) 0.1224±0.0016	3.7	17.2	59.5	27.0	≈0.05	≈310
Type II Medium Surface Area (M	(SA)					
1 (RC15-125B) 0.6806±0.0057	1.6	15.5	53.7	21.8	≈0.05	82
2 (RC15-125D) 0.7231±0.0081	0.9	10.2	28.8	13.9	≈0.05	100
3 (RC15-125F) 0.7130±0.0074	1.2	11.8	50.8	20.4	≈0.05	210
3R (RC15-126F) 0.7034±0.0074	1.5	13.0	53.2	20.2	≈0.05	180
4 (RC15-126B) 0.6183±0.0068	1.3	12.2	63.9	23.5	≈0.05	220
5 (RC15-126D) 0.7232±0.0075	2.0	17.7	68.9	27.6	≈0.05	180
Type I High Surface Area (HAS)						
1 (RC15-124E) 1.1128±0.0113	0.4	5.0	19.9	7.8	≈0.04	50
2 (RC15-124C) 1.2799±0.0123	0.2	4.2	17.7	6.6	≈0.04	40
3 (RC15-124A) 1.2147±0.0113	0.5	6.9	18.9	8.6	≈0.05	45
3R (RC15-124B) 1.0956±0.0117	0.7	7.3	19.3	8.9	≈0.05	45
4 (RC15-122C) 1.0280±0.0108	0.3	4.7	17.0	6.9	≈0.04	45
5 (RC15-124D) 1.1597±0.0114	0.3	4.3	16.5	6.5	≈0.04	40

From Phase 1 Report, Ceramatec



Synthesized Products







ICP results



Description	Si (theo)	Si(XRF)	Si(ICP) ± 1.6%	Ca (theo)	Ca(XRF)	Ca (ICP) ± 2.6%	Fe (theo)	Fe (XRF)	Fe (ICP) ± 1.8%
Run 1	58.4	58.23	58.6	41.6	40.42	39.7	0.00	0.36	0.10
Run 2	64.3	64.79	64.9	35.7	34.21	34.3	0.00	0.32	0.20
Run 3	62.4	63.85	62.9	34.6	32.56	33.1	3.00	2.87	2.90
Run 4	60.5	56.72	59.3	33.5	35.78	31.6	6.00	6.71	6.00
Run 5	61.4	59.93	59.6	34.4	35.85	30.2	2.56	3.14	2.70
Run 3R	62.4	60.84	57.6	34.6	35.11	30.8	3.00	3.37	3.20
Affival		58.6	55.9		34.4	26.2		5.58	4.80
CO 40214 - production lot	, 59.8	59.8	58.1	, 29.6	33.3	26.6	, 2.95	4.77	4.20
Topth 1205		59.1	56.7		32.7	23.6		5.45	4.80
Topth 1129		58.9	55.2		33.4	24	_	5.1	4.70
Perkins -7		58.6	53.8		36.6	26.1		3.79	3.20
Perkins -140		59.4	55.1		34.7	24.3		3.54	3.50

- Procedure developed and carried out by Crane Naval Warfare Center
- Within error, samples of interest still fall within MILC-324C elemental specifications.
- ICP recommended as technique to supplant/augment MIL-C-324C



DOE for Testing Synthesized CaSi₂



Screening DOE (10 runs + 2 standards)							
Primer mix	Milling	Sample					
1	standard	mix					
2	Υ	1					
3	N	3					
4	Y	2					
5	Y	4					
6	N	2					
7	N	1					
8	N	4					
9	Y	3					
10	Y	3*					
11	N	3*					
12	standard	mix					

- DOE resolves 3 independent, noninteracting factors: effect of milling (SA), silicon content, and iron content.
- Samples
 - 1 CaSi₂ Stoichiometric
 - 2 CaSi₂ eutectic (~5% excess Si)
 - 3 3% free iron
 - 4 6% free iron
- Milling
 - N Sieved to MILSTD Type II, SA < 1m²/g
 - Y Milled and sieved to MILSTD Type
 II, SA > 1 m²/g
- * denotes no TNR pretreatment
- Primers will be fired and performance gauged by pressure-time, impulse, and sensitivity data.
- Full cartridge tests to be performed with downselected candidates.



Conclusions



- Existing calcium disilicide fully characterized in an effort to understand chemistry
- Calcium disilicide synthesized successfully using rotary atomization from downselected characteristics of commercial lots
- Varying compositions delivered for primer assembly; variables to be tracked using statistical DOE
- LSA and MSA 3% and 6% Fe showed equivalent small scale sensitivity to production lot.

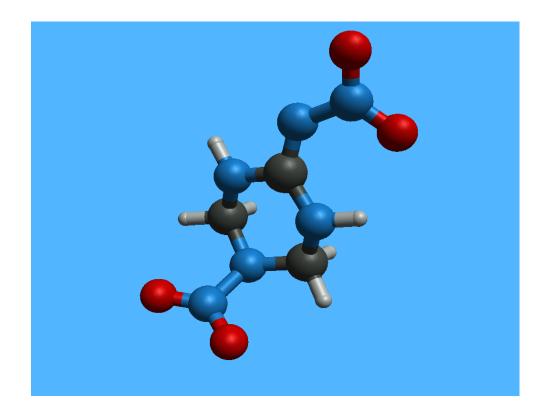
Path Forward



- Carry out primer testing at ARDEC sensitivity, performance by end 4Q09
- Integrate ICP procedure developed by Crane Naval Surface Warfare Center into MIL-C-324C by end 4Q09
- Further investigate role of passivation layer in CaSi₂ based systems
- Chemistry of calcium disilicide in primers will (perhaps) be understood!

Synthesis and Characterization of NNHT (2-Nitrimino-5-nitro-hexahydro-1,3,5-triazine)

Dr Eamon Colclough 2009 Insensitive Munitions & Energetic Materials Technology Symposium



13th May 2009

Contents

- **01** Objectives
- 02 Downselection
- 03 NNHT
- 04 Conclusions
- 05 Acknowledgments



01 Objectives

To examine a number of new energetic materials to determine the feasibility of scaling up from a few grammes to kilogramme quantities.

This was to involve two aspects:

- looking at improving procedures for synthesis of materials which are commercially available;
- looking at new cost effective synthesis routes to materials which are novel or less well developed.

The programme therefore addresses factors such as

- availability of raw materials,
- cost of raw materials
- synthetic routes
- practicality and safety of scale up



44 Heterocyclic explosive compounds added to database

Selection (initial) of ~10 candidates:

 Criteria included: Explosive output; Thermal stability (>200°C); Compatibility; Ease of synthesis; Available starting materials; Not yet commercialised

Initial selection refined to 5, subsequently 3 candidates:

- Oxadiazole (CL-14); hexahydro-s-triazine (NNHT); pyrazine (ANPZ-i)
- Further selection criteria:
 - Effluent analysis
 - Handlability
 - Scalability

$$NH_2$$
 NO_2
 NH_2
 NNH_2
 NO_2
 NNH_2
 NO_2
 NNH_2
 NO_2

02 Downselection – CL-14 Synthesis

62.9% CL-14

02 Downselection – ANPZ i Synthesis

02 Downselection – NNHT Synthesis

CL14

3-step route (more complicated)

Energizing groups introduced at start of process

requires HAZOP to be carried out earlier (stage 1/2)

Reaction control:

- precise temperature control required, particularly step 1
- efficient stirring required (all steps)

Efficient filtration of product & penultimate compound required

Safe handling of product & penultimate compound problematical

Automation not possible (stage 2/3 and beyond)

Waste disposal problem (azides, explosives)



ANPZ-i

4-step route (more complicated)

Reproducibility problems

Intermediates unstable to heat/air

One step (amination) requires autoclave (confinement problem)

Large amounts of by-products (cf. pharma processes)

Automation not possible

Waste disposal problem

Difficult and probably uneconomic to progress beyond stage 2

Alternative route required to ANPZ-i



NNHT

Reaction time should be <8 hr.

Recent results suggest:

- 3 hr. feasible
- yield not reduced appreciably

"Standard" equipment satisfactory

Few other problems anticipated on scale-up to stage 3 and beyond

Automation possible



Comparative data for three candidate compounds:

	CL-14	NNHT	ANPZ-i
Pcj (GPa), predicted	33.3	29.3	34.9
Temp. of ignition °C	307	217	n/a
Impact sens. (BAM)	Insens.	Insens.	n/a
Friction sens. (BAM)	Insens.	Insens.	n/a
Ease of synthesis*	-	++	
Effluent*		+	
Handlability*	-	+	n/a
Scalability*	-	+	n/a

*Key: ++ (best) $\leftarrow \rightarrow$ -- (worst)

Result: NNHT is preferred candidate

03 NNHT



03 NNHT – Synthesis routes

03 NNHT – Synthesis routes

Summary of status of respective routes:

t-Butylamine (NBHT) route:

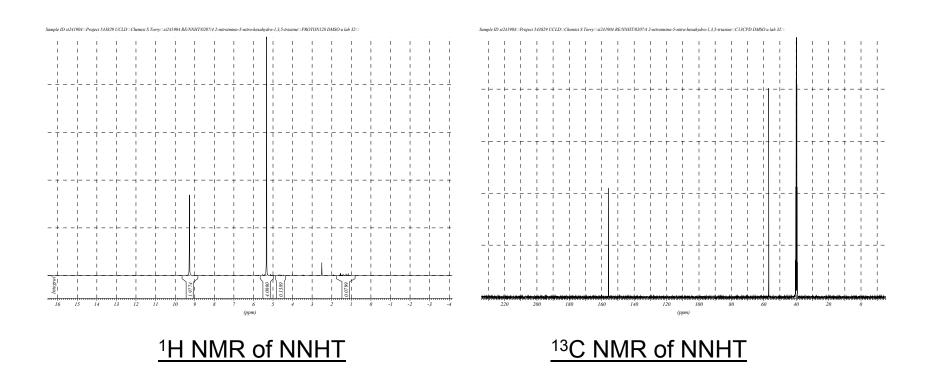
- Reaction time of 1st step shortened from 16 hr to 3 hr without loss of yield or purity
- Mild exotherms during nitration reaction investigated

Hexamine (NIHT) route:

- Optimisation of 1st step completed (HCl concn. crucially affects yield)
- Nitration (2nd step) problematical:
 - NNHT isolated but yield strongly dependent on reaction conditions, esp. temperature
 - Products other than NNHT isolated (trinitro compound?)
 - Severe exotherm problem



NMR spectra for NNHT - shift values matched those reported in the literature



Hazard tests showed that:

- Slight differences between crude NNHT (prepared via NBHT) and the recrystallised material are manifested
- These were judged to be insufficient to require a reassessment of the handling precautions for this material.



Lit. impact sensitiveness of NNHT appears to be influenced by the recrystallisation solvent used:

- Australian work (for NNHT recryst. from acetone Dagley et al. *J. Energetic Materials* 1995, <u>13</u>, 35)
 - Rotter figure of insensitiveness (F of I): 55 (cf ours 83)
 - Relative explosiveness low (from gas volumes)
 - Hazard ranking: NQ < NTO < NNHT < RDX
- Russian work (for NNHT recryst. from water Astachov et al. Proc. Symp. NTREM Pardubice 2005, 430)
 - Sensitivity "comparable to PETN"



These data, particularly Russian, conflict with our measurements

- Possible reasons:
 - Change of recrystallisation solvent
 - Methods of measurement (Russian)



Precipitation of NNHT from NMP solution effects a partial purification

NNHT can be effectively purified by recrystallisation from cyclohexanone

Recrystallised NNHT passes the vacuum stability test

Particle sizes have been measured for recrystallised (38µm) and precipitated (11.8µm) NNHT

Density of NNHT is in accord with literature 1.75gcm⁻³



03 NNHT – Cook off

Small-scale cook-off tests: preliminary results:

- Run 1 (slow): Cook-off temp. 174.5°C; behaviour Type IV
- Run 2 (slow): Cook-off temp. 173.2°C; behaviour Type III
- Further test results awaited

Conclusion:

- NNHT shows behaviour more benign than Debrix 18AS (RDX-based)
- Subject to further testing, NNHT formulations may be suitable for application in IM



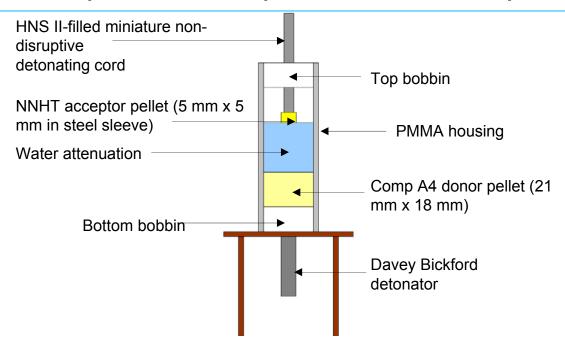
03 NNHT – Explosive cord testing

Small-scale cord Testing:

- The cord sustained detonation down to the smallest external diameter tested,
 0.7 mm.
- Aluminium sheathed cords had a VOD of approximately 6.6 km/s which was sustained as the diameter was reduced.
- In contrast the lead sheathed cords showed lower VOD below 4 mm. The VOD in lead was much lower than in aluminium but this is as expected from previous results.
- The results indicate than NNHT can be used for applications in explosive train technology, even miniaturised systems at the scale of a few mm.



03 NNHT - Explosive Component Water Gap Testing:



ECWGT Apparatus

The ECWGT results for NNHT, compared to those for other IHEs tested (e.g. HNSIV, NONA), indicate that NNHT compares favourably with the all of the materials previously tested.

The potential of NNHT for use in initiator applications, such as laser-driven flyer or exploding foil initiators, is being examined.



03 NNHT - Exploitation

Exploitation path

 The potential of NNHT for use as a gun propellant additive, in conjunction with varying amounts of RDX, plasticiser and energetic binder (polyNIMMO) was investigated by modelling. The cases of artillery and tank gun applications were investigated separately.

NNHT	polyNIMMO	RDX	K10	Tf (K)	Impetus (MJ kg)	Mw (g/mol)	volume (cc/g)	Gamma	CE (MJ/kg)
Artillery	cf NQ			2830	1.051				
35	20	40	5	2797	1.143	20.341	1.193	1.2705	4.2255
25	30	40	5	2531	1.068	19.699	1.221	1.2773	3.8514
Tank Gun	cf FX			3420	1.168				
25	10	60	5	3322	1.271	21.735	1.132	1.2541	5.0020
25	20	50	5	2913	1.177	20.588	1.178	1.2664	4.4182



03 NNHT – Scale up assessment

Scale-up aspects – Summary

- Study of the first step (NHBT formation) indicated that:
 - The reaction was not strongly exothermic
 - The synthesis should work in a 20 L reactor (making ca. 1.2 kg NBHT)
 - No 'show-stoppers' were identified in the process



03 NNHT – Scale up assessment

Study of the second step (nitration of NBHT to NNHT) indicated that:

- The reaction shows a strong exotherm, occurring on addition of the catalyst
- The reaction is more exothermic (~2x) than typical aromatic nitrations
- The control of the exotherm could be problematic, possibly mitigated by:
 - Pre-mixing of the ammonium catalyst with the nitric acid, or
 - Use of a flow reactor configuration to improve heat transfer and reduce inventory
- A 20 L reactor, made of acid-resistant stainless steel, could be used at 1 kg per run



03 NNHT – Scale up assessment

Study of the recrystallisation step indicated that:

- A number of precautions would be necessary to ensure smooth and safe operation
- No 'show-stoppers' were identified in the process



04 Conclusions



04 Conclusions

Programme: carried out and delivered according to the plan

- One lower energy candidate (NNHT) has been synthesised successfully and has now been evaluated
- The most suitable route for scale-up of NNHT (via NBHT) has been evaluated
- · Characterisation and purification studies are complete
- Initial scale-up studies are complete and show that scale-up is feasible
- NNHT has potential as a novel insensitive ingredient for propellant and explosive train applications



05 Acknowledgments

All partners in RTP14.10

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Ross Millar, Javid Hamid, Robert Endsor, Anthony Arber, Simon Torry

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Dstl

Dave Tucker

Defence Technology and Innovation Centre of the UK MOD









Synthesis of New Energetic Melt-Pour Candidates

Dr. David Price*, Dr. Jacob Morris

BAE Systems/HSAAP

May 2009





Background

- TNT has been the backbone of melt-pour explosives for most of the 20th century.
 - Not IM enough for today's standards
- DNAN is:
 - quickly becoming the favored replacement for TNT due to its superior IM properties.

not very energetic and performance of DNAN-based explosives

suffer as a result.

- Future melt-pour energetics need to have best of both worlds:
 - Superior IM properties
 - Good explosive performance







Program Objectives

- Identify and Prepare New Melt Pour Ingredients with Inherent Comp B Performance
- Evaluate Candidates Using Small Scale Safety and Performance Testing
- Evaluate Scalability of Synthesis
- Evaluate Formulation Characteristics

Selection Criteria:

- Melting Point in Desired Range (80-120C)
- Sufficiently High Predicted Density
- Perceived Ease of Preparation









Candidates compounds

DNP

m.p. ~ 85°C calc. dens. ~ 1.87 g/cm³ energy out ~ 1961 cal/cm³

3 steps

MTNI

m.p. ~ 82°C calc. dens. ~

energy out ~

6 steps

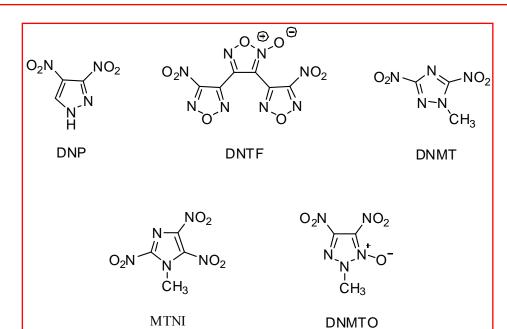
DNMTO

m.p. ~ 130°C

calc. dens. ~

energy out ~

2 steps



DNTF

m.p. ~ 108 °C calc. dens. ~ 1.95 g/cm³ energy out ~ 2517 cal/cm³

4 steps

Comp B energy out ~ 1837 cal/cm³ LX-14 energy out ~ 2186 cal/cm³

DNMT

m.p. ~ 95 °C

calc. dens. ~ 2.10 g/cm³ energy out ~ 1739 cal/cm³

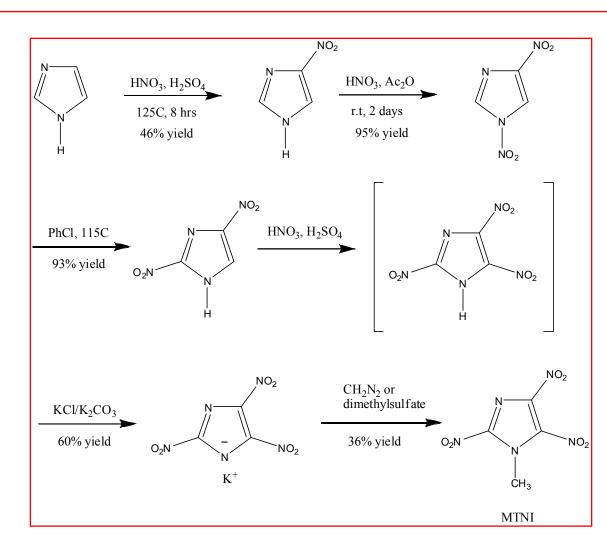
2 steps





MTNI

- Original process:
 - Complicated (6 steps with methylation)
 - Low yielding (9% to 18%)
- Lots of effort on finding entirely new route to:
 - Avoid highly toxic chemicals
 - Minimize steps
 - Increase producibility
- Bottom line:
 - Didn't find a better way

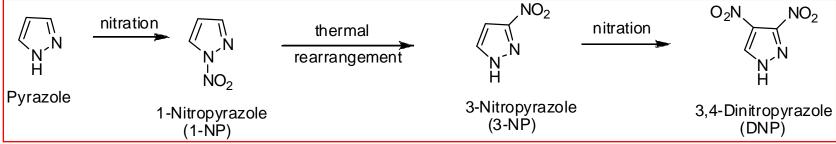




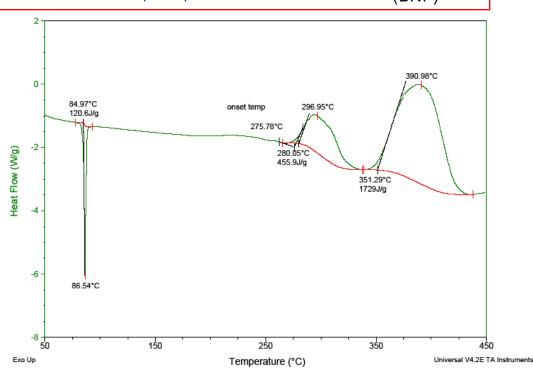




DNP



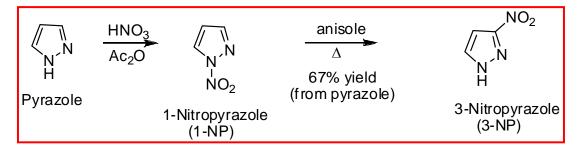
- Original process:
 - Used low concentration in thermal rearrangement
 - Used extraction in final work-up (not scale-up friendly)
 - Otherwise, not bad procedure

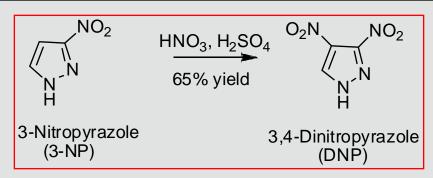






DNP Improvements





- Reduced H2SO4
 - Majority of DNP precipitates from solution
- •Recrystallize with common inexpensive solvents
- •40% overall yield from pyrazole
- •5 lbs. produced

- 1st step:
 - Nitration; acetyl nitrate in situ
 - 1-NP sublimes at ambient pressure (difficulty drying)
- 2nd step:
 - Used anisole/water azeotrope to remove water
 - ARC studies confirmed safe range
 - <40% in anisole @ high temperature.
- 67% yield of 3-NP based on pyrazole

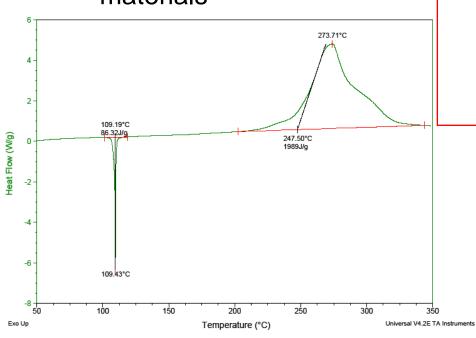


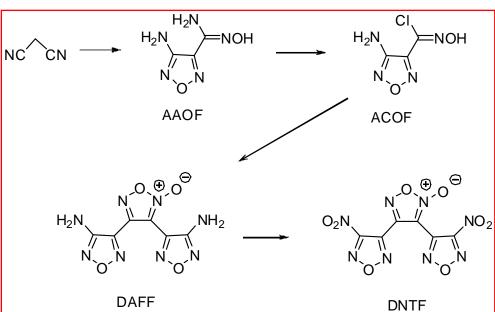




DNTF

- 4 step process
- Commercially available and affordable starting materials

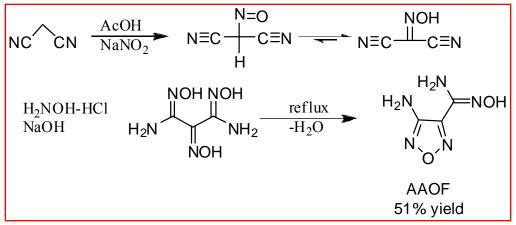








DNTF



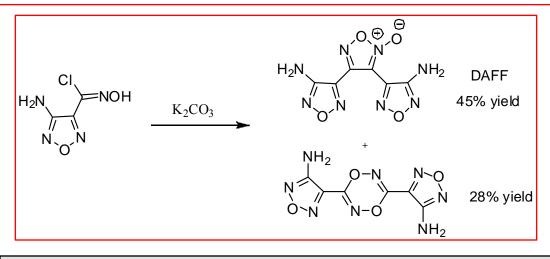
- Straightforward 3 step, 1 pot synthesis
- Scalable; several 1 kg batches
- 50% yields
- 90% yields reported when pH is tightly controlled during H2NOH-HCl addition

- Diazotization/substitution
- Stable diazonium salt intermediate
- Product a severe skin and respiratory irritant
- Transfer wet to next step; no isolation
- Scalable; ca. 1 kg produced
- 50% yields, unoptimized





DNTF



- Heterogeneous; slurry in MTBE
- Low temperature
- Usually 2:1-DAFF:DAFD
- 50% yields of DAFF, not optimized
- Scalable with improved temperature control; 0.5 lbs produced

- Strong oxidation conditions required
- 24 hrs. @ ambient
- App. 50% isolated yield
- Isolation/purification problematic
- 99% yields reported by Dong, et al. using same reagents
- Optimization of conditions? Time and temperature?







DNMTO

- MTO procedure from Prof. Begtrup, et al
 - Poor yield reproduced independently by Prof. Katritzky's group at UF
 - No improvements could be made
- Although reported nitration is high yielding, our efforts did not go that far







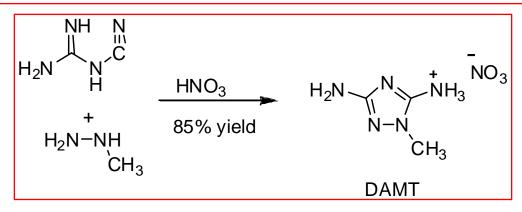
DNMT

- Original procedure:
 - Pseudo one pot reaction
 - Developed by Prof. Katritzky, et al.
 - DNMT soluble in acidic water
 - Extraction required
 - Synthesis/purification not optimized
 - 25 grams produced by this method





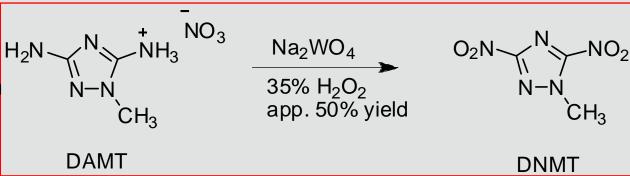
DNMT Improvements



- Moved from one-pot to two-pot sequence
- 1st step:
 - Isolation of DAMT enhanced by minimizing water in reaction
 - Product precipitates from reaction medium
 - Isolated by filtration

2nd step:

- Switching from diazotization to oxidation uses less reagents
 - DNMT precipitates
 from reaction medium
 - Product isolated by filtration









Safety Testing

ARDEC-Picatinny Arsenal

	ERL Impact (cm)	BAM Friction (N)	ESD (J)
DNP	67.4	>216	>0.25
DNTF	<15.8	>64	>0.25
DNMT	>100	>252	>0.25
RDX	25.4	>144	>0.25

OSI-Holston

Impact Sensitivity (cm), Navy Method							
	Pre-melt	Post-melt					
DNP	54.1	146.9					
DNTF	~17	<8					
DNMT	92.7	171.0					

- Melt-recrystallization might provide amorphous character
- Potentially remove crystalline defects/hot spots
- Appears valid for DNP, DNMT
- DNTF-long recrystallization time; highly crystalline







	Pcj, calc. (GPa)	Pcj, exp. (GPa)	Energy out, calc. (cal/cc)	VOD, exp. (Km/s)
DNP	28.8	29.4	1961	8.104
DNMT	25.4	23.3	1739	7.850
Comp B	27.7	~27.6	1837	~7.960
DNTF	35.9		2517	
LX-14	35.1	~37	2186	~8.800











Compatibility Evaluations

- •1:1-Mass:Mass Physical Mixtures of HSAAP Formulation Ingredients
- •DSC @ 5 °C/min. from 50 to 450 °C
- •Observe Changes in Exotherm Onset and Peak for Lowest Value Component
- •Negative Deviations ≥10 °C Indicate "Fail"; Invoke VTS









Compatibility Matrix

		DNP			DNTF			DNMT	
	MP	Exo Onset	Exo Max	MP	Exo Onset	Exo Max	MP	Exo Onset	Exo Max
NEAT	86.5	275.8	296.9	107.5	230.2	270.7	95.7	260.6	280.0
RDX MP Exo Onset Exo M 203.6 205.8 227.5		202.6	234	106.6	204.6	227.2	88.2	204.3	230.9
HMX MP Exo Onset Exo M 187.2 276.3 284.2		203.3	221.2	108.1	239.3	260.1	93.7	223.4	252.8
NTO MP		175.7	237.7	108.2	253.9	257.9	97.7	176.9	231.4
TATB MP		193.3	273.7	108.4	234.6	267.8	97.6	227.1	243.5
DNAN MP Exo Onset Exo M 94.2 326.9 342.9		203.9	302.9	68.9	241.8	271.9	54.8	301.6	322.3
NQ MP Exo Onset Exo M N/A 195.2 202.8		182.5	222.7	108.5	182.8	225.5	95.3	182.7	222.8
DNP MP Exo Onset Exo Mark 86.5 275.8 296.9				78.3 /102.1	208.5	248.7	46.25	285.4	345.6
DNTF MP Exo Onset Exo Mode 107.5 230.2 270.7							81.1/92.5	233.8	268.7





Conclusions

- DNP was optimized and scaled to produce 5 lbs of material
- MTNI was discontinued due to complicated synthetic route (not easily scalable, costly)
- DNMT was discontinued although not before showing some promise of scalability and affordability
- DNMTO was discontinued due to terrible yields in first synthetic step

DNTF was discontinued due to sensitivity concerns with

final product









- RDECOM-ARDEC
 - Mr. Omar Abbassi
 - Mr. Sanjeev Singh
 - Dr. Reddy Damavarapu
 - Mr. Philip Samuels
 - Mr. Paul Vinh
- BAE Systems, HSAAP
 - Mr. Gary Clark
 - Mr. Jim Owens
 - Ms. Kelly Guntrum
 - Ms. Lisa Hale



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Innovation ... Delivered.

Laboratory Scale Nitration of Cellulose as a Cost Effective Risk Mitigation Tool for the Production of Nitrocellulose at Radford Army Ammunition Plant

Dr. Benjamin R. Vaughan, Zach Higginbotham, Dr. Anand Mangalam, Leslie Ben'Ous, Peter Bonnett May 13,2009





NITROCELLULOSE MANUFACTURING AT RFAAP

LAB SCALE NITRATION / STABILIZATION

PART I: LAB SCALE NITRATION STUDY

- MIXED ACID COMPOSITION
- KEY INPUT VARIABLES EFFECTS

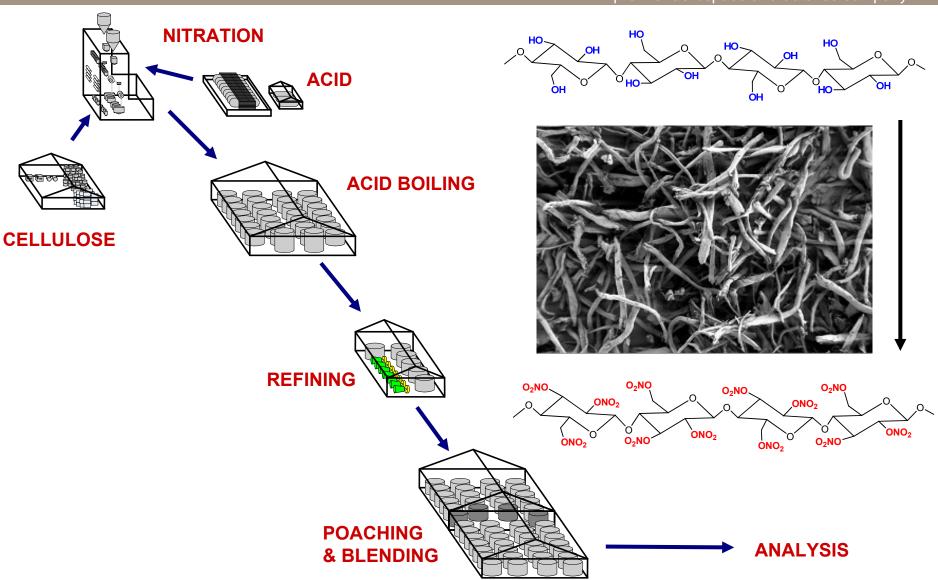
PART II: CELLULOSE SOURCE STUDY

- KRAFT VS SULFITE PULP
- ACADEMIC WORK

NITROCELLULOSE MFG. 101



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LABSCALE NITRATION



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NITRATION



CELLULOSE



ACID BOILING





POACHING



PART I: NC REACTION CONDITIONS STUDY



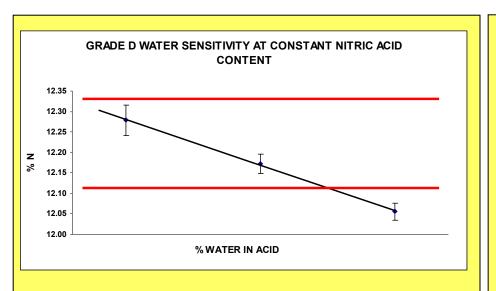
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- 1.Demonstrate that laboratory nitration can be used as a tool to aid production with risk mitigation associated with sensitive products
- 2.Understand how mixed acid composition and key process input variables (KPIV) change our nitrocellulose in terms of:
- % Average Nitrogen
- Acetone solubility, and Ether / Alcohol Solubility
- Processing of NC



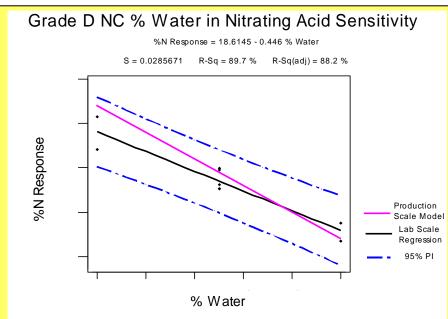
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Water sensitivity models developed for Grade D and E nitrocellulose products



Lab data shows linear response of %N to water at current process acid composition

Good fit of data to simple model



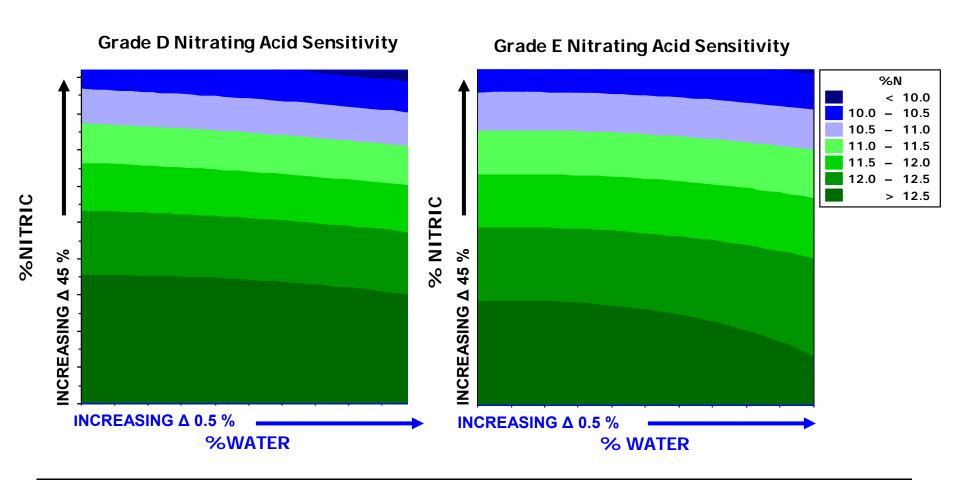
AFY09 NC production data fits within lab scale model's 95% prediction limits for Grade D NC

Process data fits have led the NC technical team to use less water set changes during manufacturing

Nitration with various mixed acids



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PRODUCTION IS CURRENTLY USING THE MODELS DEVELOPED IN THE LAB TO ADJUST NITRATING ACIDS FOR PRODUCTION OF GRADES D AND E NITROCELLULOSE

KEY PROCESS INPUT VARIABLES AFFECTING ATK NC



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Run	Time (min)	Temp (°C)	A/C Ratio	Cellulose	%N	Al	EA %Sol	%N	Al	EA %Sol
						GRADE E			GRADE D	
1	HIGH	LOW	HIGH	Chips	12.051	0.21	99.70	12.315	0.93	98.93
2	HIGH	HIGH	HIGH	Fibers	12.038	0.19	99.71	12.251	0.59	98.28
3	MID	MID	MID	Fibers	11.740	0.59	98.70	12.182	0.22	99.18
4	LOW	HIGH	LOW	Fibers	11.740	0.91	97.78	12.040	1.16	97.57
5	HIGH	HIGH	LOW	Chips	11.819	0.10	99.94	12.105	0.07	99.66
6	HIGH	LOW	LOW	Chips	11.804	2.30	97.78	12.038	4.15	95.46
7	LOW	HIGH	HIGH	Chips	12.043	1.14	98.65	12.371	0.93	99.14
8	LOW	LOW	HIGH	Fibers	11.809	1.93	93.71	12.235	2.50	93.72
9	LOW	LOW	LOW	Chips	11.714	15.68	79.66	11.865	11.94	86.92
10	MID	MID	MID	Chips	11.985	0.26	99.74	12.306	0.14	99.80

VARIABLE	RESPONSE			
(NITRATING ACID MAKEUP FIXED)	Al	EAS	%N	
ACID \ CELLULOSE				
TEMP.				
TIME				
CHIPS OVER FIBERS				



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Answer two Questions:

- 1. Is it feasible to make nitrocellulose from Kraft paper? Which pulp candidates look most promising?
- 2. Why do similar pulps nitrate so differently? What are the key cellulose characteristics influencing nitration?
 - Hemicelluloses content
 - Crystallinity
 - Fiber wall thickness
 - Tree species used
 - Sheet Physical Properties

TWO MAJOR PULPING PROCESSES



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SULFATE (KRAFT)

- Basic digestion
- •Universal process for recovery of cooking chemicals
- Dominant process
- •Cost ~ \$ 0.20 / lb
- Use most types of trees



- Acidic digestion
- •Limited recovery of acid gas
- •Mills diminishing
- •Cost ~ \$baseline
- •Use limited tree species



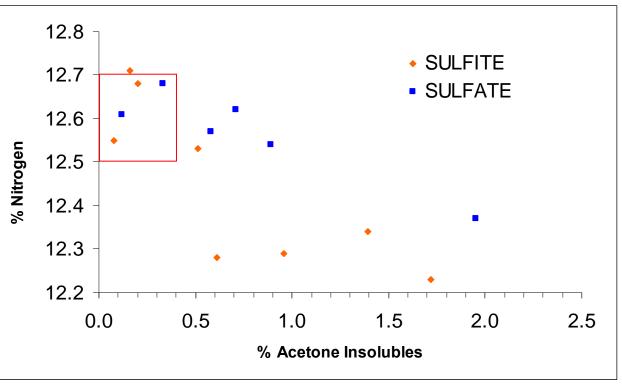


NITRATION QUALITY AND SOLUBILITY



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% NITROGEN = 12.6 + 0.1% , ACETONE INSOLUBLES < 0.4%



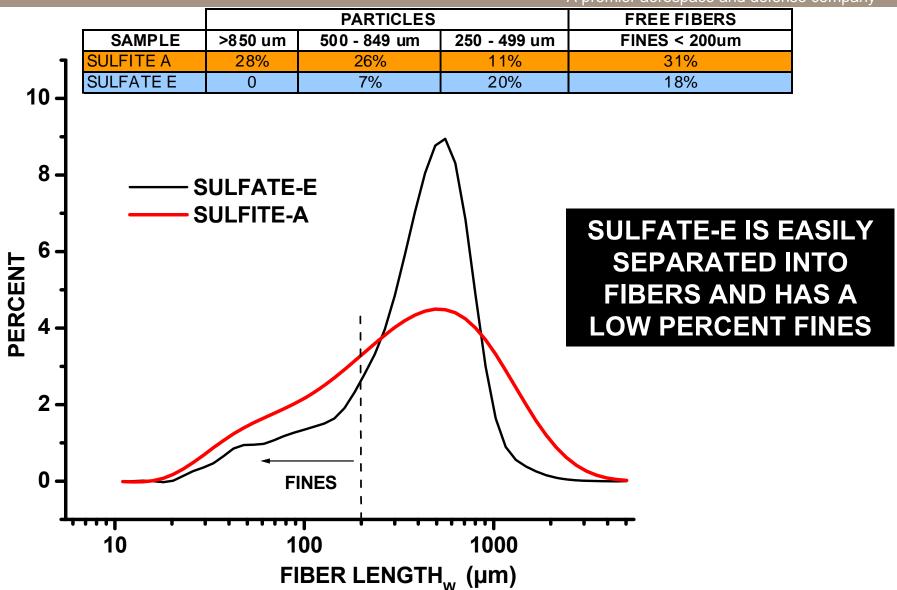
	%N (FeSO ₄)	%AI	%EAS
SULFITE A	12.68	0.2	99.8
SULFITE B	12.28	0.6	98.9
SULFITE C	12.23	1.7	97.1
SULFITE D	12.53	0.5	99.3
SULFITE E	12.55	0.1	99.9
SULFITE F	12.29	1.0	98.4
SULFITE G	12.71	0.2	99.9
SULFITE H	12.34	1.4	97.9
SULFATE A	12.57	0.6	99.3
SULFATE B	12.62	0.7	99.1
SULFATE C	12.37	2.0	97.5
SULFATE D	12.54	0.9	98.9
SULFATE E	12.61	0.1	99.8
SULFATE F	12.68	0.3	99.8

SEVERAL OF THE SULFATE PULPS TESTED TO DATE APPEAR TO HAVE PROPERTIES THAT MEET MILITARY GRADE NC SPECS

FIBER QUALITY



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WOOD PULP FIBERS



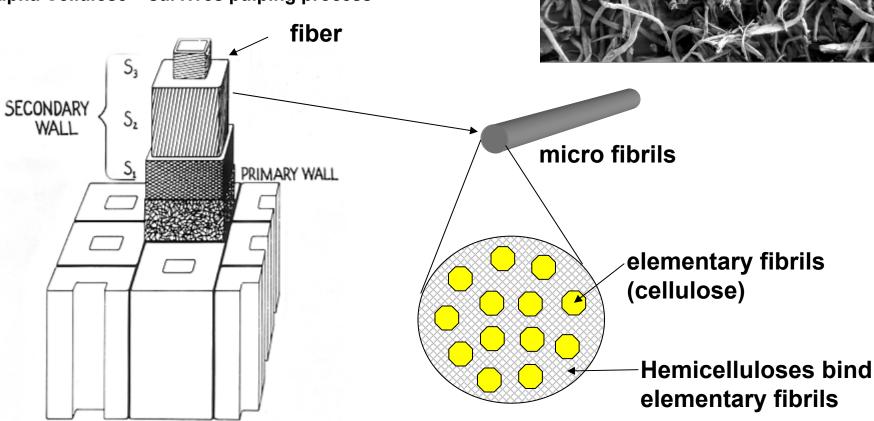
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Resin (Extractable) – can survive the pulping process

Lignin – (binder) likely removed during the pulping process

Hemicelluloses (polysaccharides) – can survive pulping process

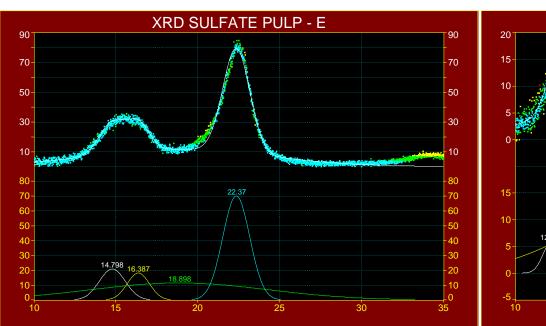
Alpha Cellulose – survives pulping process

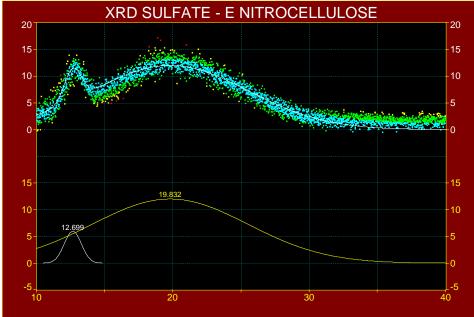


CRYSTALLINITY % AND HEMICELLULOSE %



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60% CRYSTALLINITY

5% CRYSTALLINITY

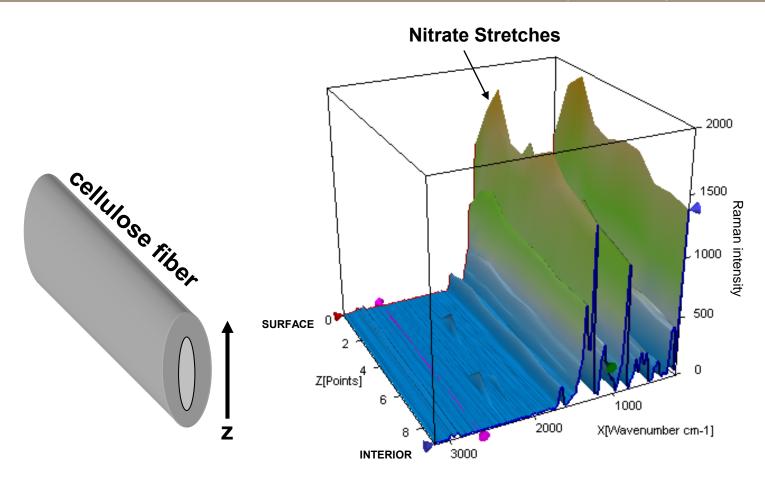
SULFITE PULPS	SULFATE PULPS			
AVG HEMICELLULOSES = 5%	AVG HEMICELLULOSES = 19%			

NEITHER CRYSTALLINITY OR HEMICELLULOSES CONTENT APPEAR TO BE MAJOR FACTORS IN THE NITRATABILITY OF CELLULOSE

CONFOCAL RAMAN MICROSCOPY



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WE ARE COMPARING THE NITRATION LEVEL AT DIFFERENT DEPTHS WITHIN THE FIBER WALL FOR DIFFERENT PULP SAMPLES



•WE HAVE BEEN ABLE TO PERFORM NITRATION EXPERIMENTS AT THE LAB SCALE WHICH WOULD HAVE BEEN DIFFICULT, TIME CONSUMING, AND EXTREMELY EXPENSIVE AT THE PRODUCTION SCALE.

•LAB SCALE NITRATION HAS BEEN AN EFFECTIVE METHOD FOR TUNING NITRATION CONDITIONS FOR THE PRODUCTION SCALE PROCESS.

•LAB SCALE NITRATION IS HELPING ATK TO ASSESS FUTURE SOURCES OF CELLULOSE FOR NC PRODUCTION AS WELL AS ANSWERING SOME FUNDAMENTAL QUESTIONS.

We would like to thank PM Joint Services and ARDEC for funding the cellulose source study portion of this research.

Innovation ... Delivered.

2009 NDIA IM/EM Meeting Tucson, AZ – May 11-14, 2009

"1,2,4-Butanetriol Production at ATK – A Sustainable Solution"

Dr. Andrew Sanderson, Dr. Steve Velarde ATK Energetic Systems



Why Synthesis at ATK Energetic Systems



A premier aerospace and defense company

✓ History

- ATK has operated RFAAP since inception and intends to be the operating contractor of the future
- Recent history has shown small companies to be a risk of single point failure

✓ Commitment

- ATK is dedicated to safety, quality, and excellence in all that we do
- ATK has and will continue to support the DoD and NTIB contractors
- ATK has invested heavily in upgrading & expanding facility capabilities

✓ Quality

- ATK has a world class Specialty and Flexible Energetics Facilities
- We met all quality requirements for BT every time
 - From initial small scale lab synthesis to 10l scale
- Systems and talent in place to ensure quality is maintained through scale up

ATK Energetic Systems is committed to serving the warfighter: past, present, and future!

A premier aerospace and defense company

- 1,2,4-butanetriol (BT) is a straight chain polyol (similar to glycerin)
- Multiple synthetic routes to BT are known, but purification is key
- BT is the precursor to BTTN
- BTTN is an energetic plasticizer used in several propellants
- BTTN is lower melting and less sensitive than NG

BT is a simple molecule that is not so simple to obtain

A premier aerospace and defense company

The sad story of BT – an orphaned chemical

- Pre-2002: Avecia is qualified CONUS BT supplier
- 2002: Copperhead Chemical is re-qualified as BTTN supplier
- 2002-2003: Avecia sells business segment that produces BT to Cytec
 - Cytec assures Copperhead that BT production will continue
- 2003: Cytec discontinues BT production;
- May 2008: ATK Energetic Systems answers Sources Sought with a BT production solution
- November 2008: ATK Energetic Systems delivers high purity BT sample for evaluation
 - Purest BT ever evaluated by Copperhead Chemical
- March 2009: ATK begins BT process development and scale-up activities

Reliance on commercial sources outside of the NTIB puts the government at risk

ATK BT requirements



A premier aerospace and defense company

Meet or exceed Mil Spec requirements

High Purity >98% (GC)

Boiling point ca. 170C at 8-10mmHg

No new trace contaminants

Optically inactive

Low cost reagents

Robust synthesis

History of NG explosions from impure glycerin

Readily available materials and reagents

Readily scaled up in NTIB facilities

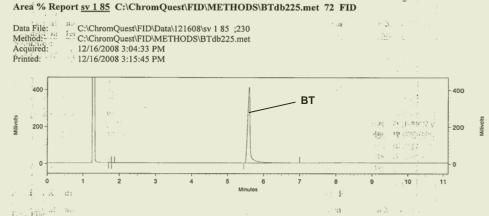
Plan to Identify and Meet Requirements First Time

ATK BT Process Summary



A premier aerospace and defense company

- √ Two step process is amenable to scale-up
 - -Robust process with good yields
- ✓ BT from AES meets internal requirements
- ✓ BT process development and scale-up ongoing
 - -Leveraging extensive ATK resources
 - -Partnering with ABL on scale-up effort



- √ Rapid development at lab scale
 - -Key proprietary purification step has been developed at AES
 - -Several pounds of BT purified



Acid catalyzed esterification

Choice of starting material, alcohol (methanol/ethanol), catalyst and reaction conditions

Desire

- Low cost reagents
- Rapid and complete reaction
- High reactor loading
- Simple work up

Result

- Low cost four carbon optically inactive natural product
- Clean reaction under simple conditions

Reaction optimized to rapidly give high isolated yield of pure ester



A premier aerospace and defense company

Hydride reduction

- Choice of reagents and conditions
- Wide range of solvents in literature

Desire

- Safe and complete reaction
- High reactor loading
- Simple work up

Reaction optimized to give high purity in crude mixture and moderate isolated yield of pure BT

- Crude BT may contain boron from reduction
- Expect yield to increase at larger scale

A premier aerospace and defense company

Status and plans



Lab studies complete

- Optimization of esterification at lab scale
- Optimization of reduction of ester at lab scale
- Purification of crude alcohol at lab scale

Scale up in pilot plant

- Esterification already conducted in pilot plant
 - No changes anticipated moving to 100 gallon reactor
- Reduction already conducted in pilot plant
 - Potential for further improvement in Pfaudler reactors
- Purification scale up to be done

Will scale all steps to 100 gallon by July 2009





Acknowledgements



- Drs. Jamie Neidert and Greg Drake (AMRDEC)
- Gregg Corley, Dr. Ron Clawson, and Dr. Scott Riley (ATK/ABL)
- Randy O'Brien and Peter Hartmann (ATK/RFAAP)
- John Schrader, Copperhead Chemical Co.





2009 Insensitive Munitions and Energetic Materials Technology Symposium

Qualification Testing of the Insensitive TNT Replacement Explosive IMX-101

Anthony Di Stasio
US ARMY ARDEC

13 May 2009



Acknowledgments





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Office of the Secretary of Defense (OSD)
Joint Insensitive Munitions Technology Program (JIMTP)
The US Marine Corps











PM CAS Program Objectives:

- Implementation of an EIDS* and IM Solution in 155mm Artillery
 Ammunition within 3 years
 - Reduce hazard classification from 1.1 to 1.6
 - Implement system IM solution while maintaining system performance

Explosive Technology Transition

- Provide an insensitive replacement for TNT
- Provide a fully characterized, IM compliant, and ready for full qualification explosive
- Provide an EIDS explosive solution

*Extremely Insensitive Detonating Substance





JIMTP Technology Objectives





System IM Objectives

- Demonstrate Type III response for Sympathetic Detonation (SD) without barriers at the 155mm diameter
- Demonstrate Type V response for Fast Cookoff (FCO) of an artillery round
- Demonstrate Type III/V response for Shaped Charge Jet (SCJ) at TNT energy
- Maintain system performance (e.g., Fragmentation and blast overpressure)
- Maintain acceptable production and life cycle costs (affordable and producible within industrial base)
- Characterize Slow Cookoff (SCO), Bullet Impact (BI), and Fragment Impact (FI)





Explosive Formulations



	IMX-101	IMX-102	IMX-103
2,4-Dinitroanisole (DNAN)	40		
* Proprietary *	40		45
3-Nitro-1,2,4-triazol-5-one (NTO)	20	50	
Trinitrotoluene (TNT)		35	
Wax		15	
DEMN (Nitrate Salt Eutectic)			50
RDX			5

- Formulated from common and inexpensive ingredients
- Detonation Energy equivalent to TNT
- Low Hazard Sensitivity
- Melt pour processing similar to TNT

5
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



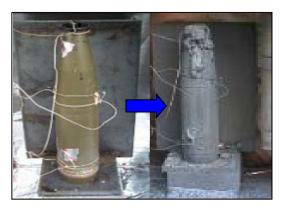
Engineering IM Tests



Fragment Impact



SCO



SCJI (50mm/81mm)





PASS

FAIL

PASS

IM Test:	FCO	SCO	BI	FI	SD	SCJI
Passing Criteria	V	V	V	V	III	III
155mm Baseline (TNT)	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
						50mm 81mm
IMX - 101	Pass	Pass	Pass	Pass	Pass	PASS PASS

PASS

FAIL

PASS

PASS

 Past program to replace TNT for artillery projectiles produced IMX-101, IMX-102, and IMX-103

PASS

Pass

PASS

Pass

Selected IMX-101

IMX - 102

IMX - 103

PASS

Pass



Explosive Producibility





Producibility

- Over 5,000 kg IMX-101 generated in production scale batches at BAE-Holston
 - One batch chosen for qualification (007)
- Artillery round load studies at ARDEC
 - Optimized artillery round loading configuration and temperature profiles
 - Produced All Up Rounds for gun launch
 - Evaluated round QA procedures
 - Refine X-ray methods and data interpretation





Energetics Qualification Program



Energetic Materials Qualification Process



- Purpose
 - Only qualified explosives will be used in munitions and devices for operational and training purposes
- Comprehensive assessment of the Energetic Material
 - Safe and Suitable for the intended use
- Assessment Includes
 - Small Scale Impact, Friction, ESD, Thermal properties
 - Ignition properties

Toxicity

Critical Temperature

Performance

Shock Sensitivity

Compatibility

Mechanical Properties

System Sensitivity (e.g., Set Back)

Sensitivity with age

From Gun Launch)



Small Scale Hazard Sensitivity





	ERL/ Bruceton Impact (cm)	BAM Friction (N)	ElectroStatic Discharge (ESD, J)	DSC (Exotherm peak; °C)	Vacuum Thermal Stability (ml/g, 100 °C/48 h)
TEST RANGE OR LIMIT	2.5 kg drop weight	80 N (Min.)	0.25 J	10 °C/min, 500 °C max	≤ 2 ml/g of gas evolved
IMX-101	> 100	240	No Go	223	0.34
TNT	88	216	No Go	300	0.10
RDX	27	168	Go	241	0.12





Critical Temperature



Nonviolent Ejection

2008-FEB-21 CTHUD 13:00:23

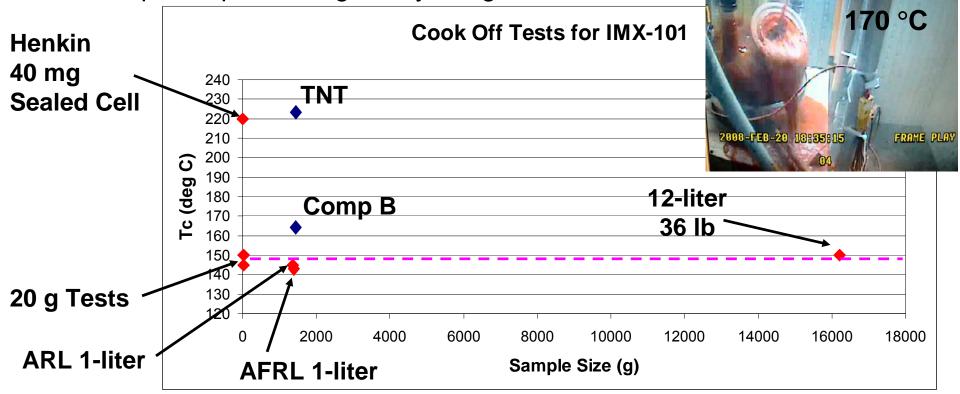
 Self Heating = Thermal decomposition of material produces heat faster than it can be dissipated to surroundings

Critical Temperature = Lowest constant temperature at which a material can

self heat catastrophically

No Scaling – same crit temp at 1-liter and 12-liter

Acceptable processing safety margin





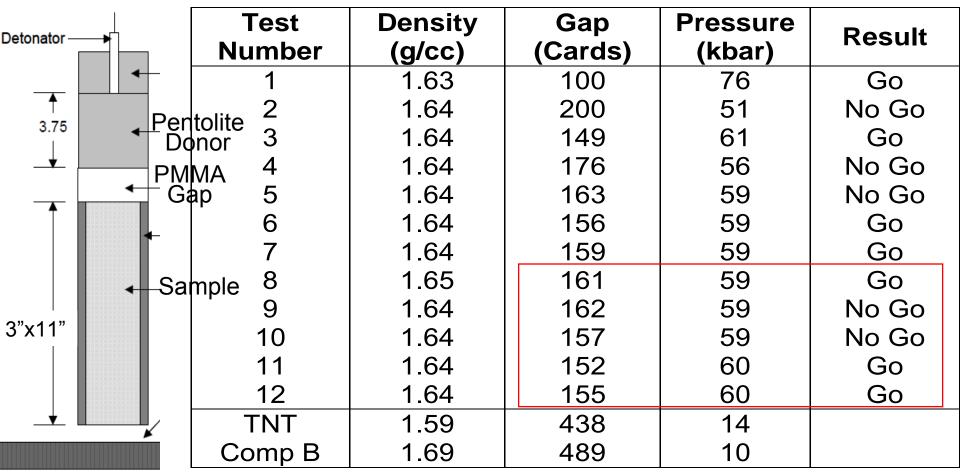
Shock Sensitivity







50% Gap Thickness

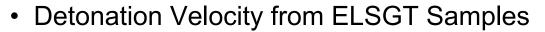






Detonation Velocity









	V	1	X	_	1	0	1
			•	١.	•	v	•

IMX-101

TNT

Det Vel	Density
(km/s)	(g/cc)
6.9	1.64
6.9	1.64
6.9	1.64















Extremely Insensitive Detonating Substance (EIDS)

- Usual Hazard Classification for Explosives is 1.1 (Mass Explosion)
 - Large quantity-distance criteria imposed for bulk storage of ammunition
 - Separation distance for 4500 kg explosive was 381 m
- Hazard Classification of 1.6 (No Mass Explosion)
 - Separation distance for 4500 kg explosive is 52 m
 - Decrease logistics burden
 - System IM objectives become more achievable with less sensitive explosive









UN Series 7 Tests

- EIDS Cap Sensitivity to shock from standard detonator
- EIDS Gap Sensitivity to a calibrated shock
- Susan Impact Sensitivity to high velocity impact while confined
- EIDS Bullet Impact 50 cal and two sample orientations
- EIDS External Fire 30 minute bonfire
- EIDS Slow Cookoff Increase temperature 3.3 °C/hr



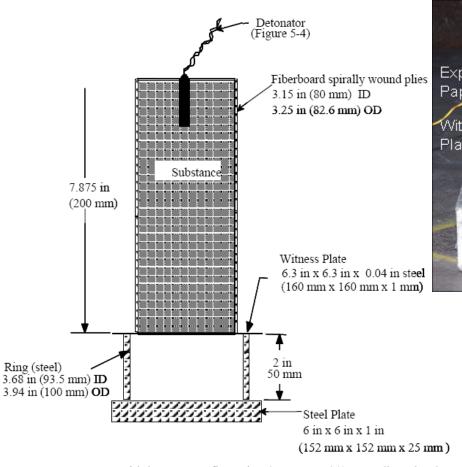








EIDS Results - Cap





No Witness Plate Penetration in 3 Trials

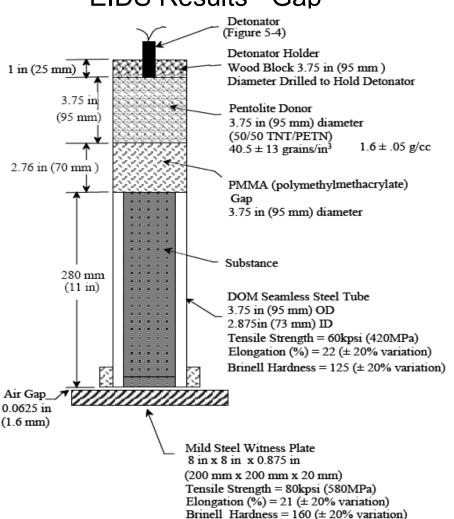
PASS







EIDS Results - Gap





No Witness Plate Penetration in 3 Trials

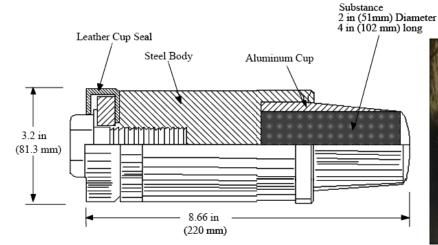
PASS

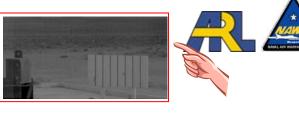
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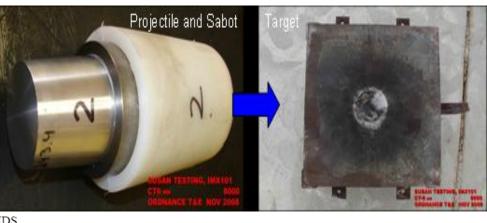




EIDS Results - Susan







Note: Projectile weight - 12 lb(5.4 kg). Contains approximately 1 lb (0.45 kg) of candidate EIDS

Figure 5-24. SUSAN Impact Test Projectile UN Test 7(c)(i)

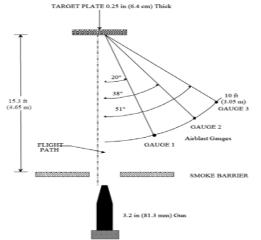


Figure 5-23. SUSAN Impact Test configuration (UN Test 7(c)(i))

PASS

- -Launch Velocities were 340 to 365 m/s
- -EIDS = < 3.9 psi blast overpressure in at least 5 trials
- -The average overpressure for six IMX-101 tests was 0.4 psi





EIDS Results – Slow Cookoff

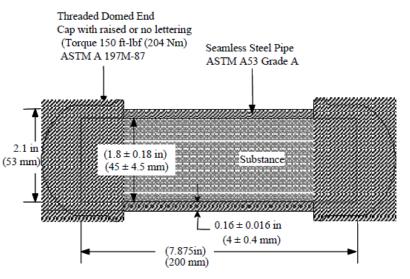
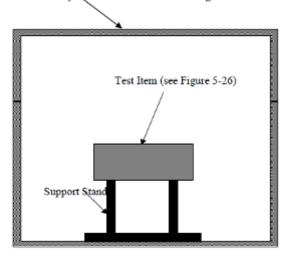


Figure 5-25. Standard Steel Pipe EIDS Test Item Thermally Controlled Oven with Venting









Fail

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Summary







- IMX-101 was fully characterized for safety and suitability in its intended use
 - Hazard testing demonstrated that IMX-101 was less sensitive than TNT
 - Critical temperature assessment indicated that IMX-101 was safe to process under typical melt pour processing conditions
 - The shock sensitivity of IMX-101 was far less than TNT
 - The IMX-101 detonation velocity was identical to TNT
- EIDS testing indicated that IMX-101 is not a candidate for 1.6
 Substance hazard classification due to a failing result from SCO testing
- The aging study will be completed this fall
- System IM testing is set to be conducted this summer







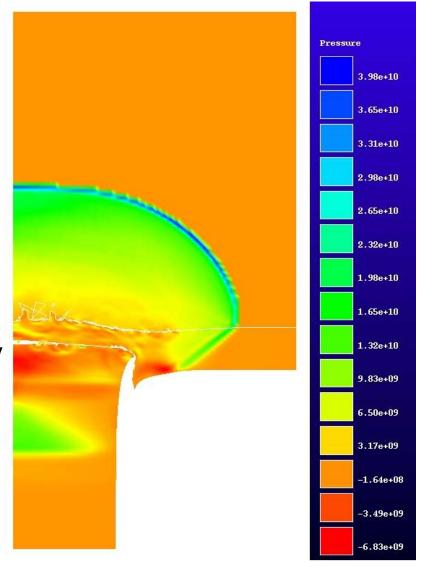




Fragment Attack of Complete and Sectioned Rocket Motors

P J Haskins, M D Cook, R I Briggs, P Ottley & M Sharp

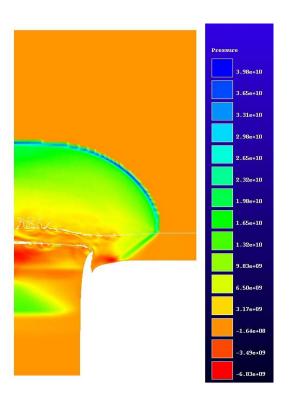
A presentation to: NDIA IMEM Technology Symposium



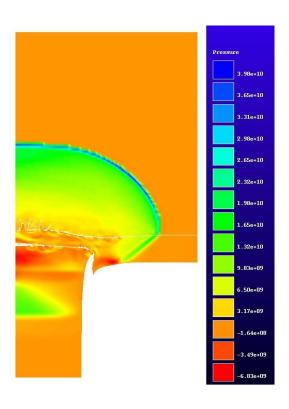


Contents slide

- **01** Introduction
- 02 Gun Systems
- 03 Rocket Motor and Sections
- 04 Instrumentation
- 05 Experimental Arrangement
- 06 Experiments on Sectioned Rocket Motors
- 07 Experiments on Complete Rocket Motors
- 08 Discussion & Conclusions



01 Introduction



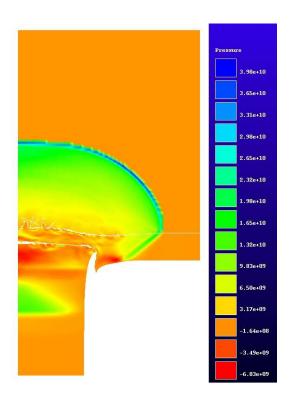
01 Introduction

High velocity fragments can pose a significant threat to weapon safety.

- •As a consequence STANAG 4496 stipulates a testing regime which requires a standard Fragment Simulating Projectile (FSP) to be fired at the weapon under test.
- •In the work presented here we have studied the response of a large rocket motor to three different FSPs. These were:
 - The STANAG FSP (a 14.3mm diameter steel rod with a 160° conical nose).
 - A 20mm diameter flat-ended steel cylindrical projectile, mass 27g.
 - A 30mm diameter flat-ended hollow-backed steel cylinder, mass 100g.
- •Most tests were carried out on sections of rocket motor although two confirmatory tests were conducted on All-Up motors with the STANAG FSP.



02 Gun Systems





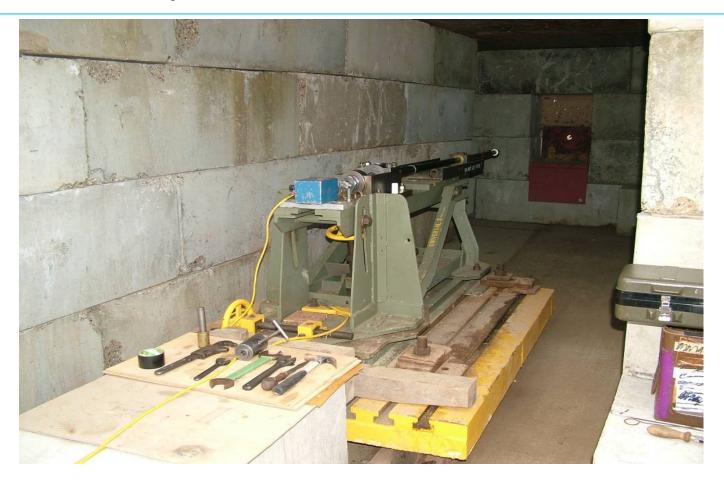
02 Gun Systems

Our approach to fragment impact testing is to use our 30mm gun for the lower STANAG velocity requirement (1830m/s) and our new 40mm gun for the higher velocity test (2530m/s).

- •Whilst the 40mm gun could be used for all velocities this approach has benefits due to reduced operating costs and faster turn around times for the 30mm gun.
- •For both gun systems the STANAG and 20mm diameter projectiles are housed in discarding plastic sabots and fired through a stripper plate to ensure that the target is not struck by sabot fragments. The 30mm FSP has a nylon driving band and was launched from the 30mm gun only.
- •The 30mm ammunition is of two-piece construction, whereas the 40mm ammunition is one-piece, with the sabot and fragment pressed into the cartridge case before loading.
- •The 40mm gun barrel is evacuated prior to firing when high velocities are required. It should be noted in this context that to achieve 2530m/s at impact with the target it is necessary to have a muzzle exit velocity of ca. 2700m/s when working at a typical muzzle to target separation of 10m.



02 30mm Gun System



02 QinetiQ 40mm High Velocity Gun



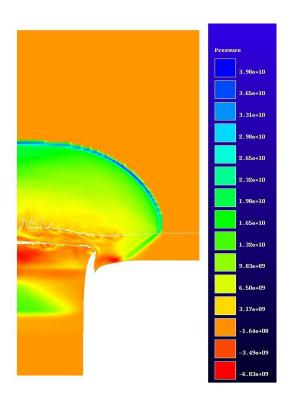


02 30mm Ammunition (left) and 40mm Ammunition (right)





03
Rocket Motor and Sections





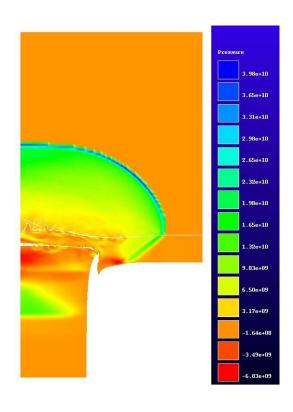
03 Rocket Motor and Sections

The rocket motor studied was ca. 2m long by 23cm diameter.

- •The propellant was an AP/Al/HTPB/iron oxide composition and the grain was centre perforated with four axial slots (broad at the nozzle end tapering to narrow at the nose).
- •The critical diameter of the propellant was considerably in excess of the motor diameter and consequently the motor was incapable of sustaining a detonation.
- The motors were cased in steel, ca. 3mm thick.
- •Four rocket motors were sectioned into samples with a length to diameter ratio of ca. 2, giving four sections per motor, and a total of sixteen sections for testing.
- Two other rocket motors were used complete for All-Up Motor fragment impact tests.
- •The motors were X-rayed before sectioning and the results indicated that the propellant grain was in excellent condition.



04 Instrumentation





04 Instrumentation - High-Speed Video Photography

All tests were filmed using high speed video (Phantom 7 cameras).

- •One camera, typically running at 100,000 frames per second (fps), was used to determine projectile velocity, projectile stability and target reaction details.
- •The events were back-lit with flash bulbs behind a diffusing screen.
- •A white board (marked with black lines to indicate one foot squares) of dimension 8 by 4 feet was placed behind the diffusing screen.
 - This board was illuminated using two further banks of seven flash bulbs.
 - The timing of these flash bulbs was arranged to occur later than the first set to capture break-up of the rocket motor casing and expansion of the products.
 - A second Phantom camera running at 47,000fps was used to capture a broader view of the target.



04 Additional Instrumentation

Blast gauges were used to assist with determining the response from fragment impact of the rocket motor charges.

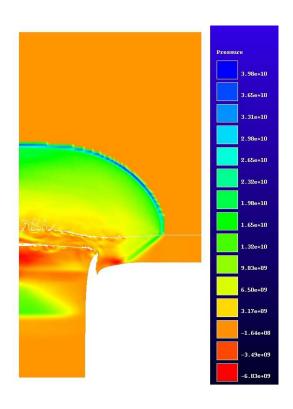
- The blast gauges were angled at approximately 45° to the shot line and spaced at 5, 10 and 15m from the store.
- Two banks of gauges were used, one set dedicated to the 30mm gun and the other to the 40mm gun.

Time-of-arrival gauges were used to measure the early phase of case expansion following fragment impact.

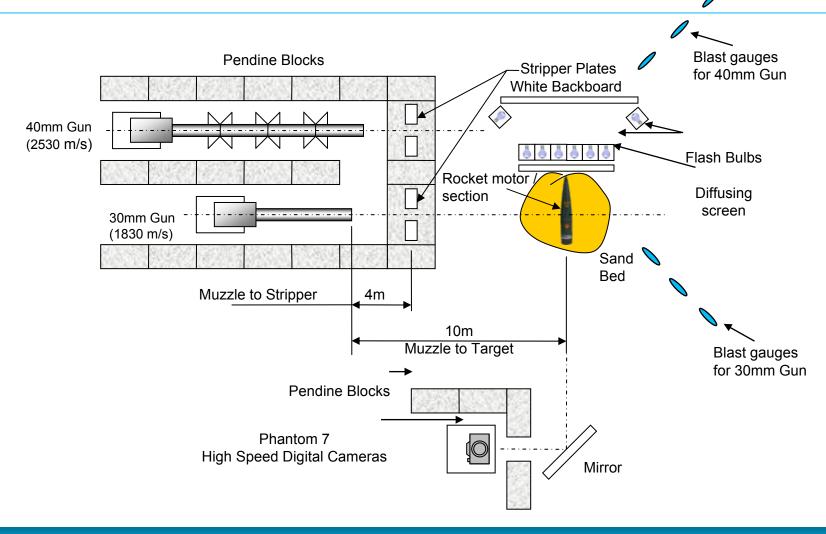
- Comprised of PMMA bar 350mm long, 50mm wide and 12 mm thick with 8 microcoaxial cables (3mm in diameter), spaced 20mm apart.
- The micro-coaxial cables were mounted such that they stood 1mm proud of the PMMA bar. Sections of aluminium foil were attached to the outer wall of the rocket motor or section casing using double sided tape.



05 **Experimental Arrangement**



05 Experimental Arrangement





05 Experimental Set-up (1)



View of setup showing:

- Rocket motor section,
- · Diffusing background,
- Flash banks,
- White backboard.

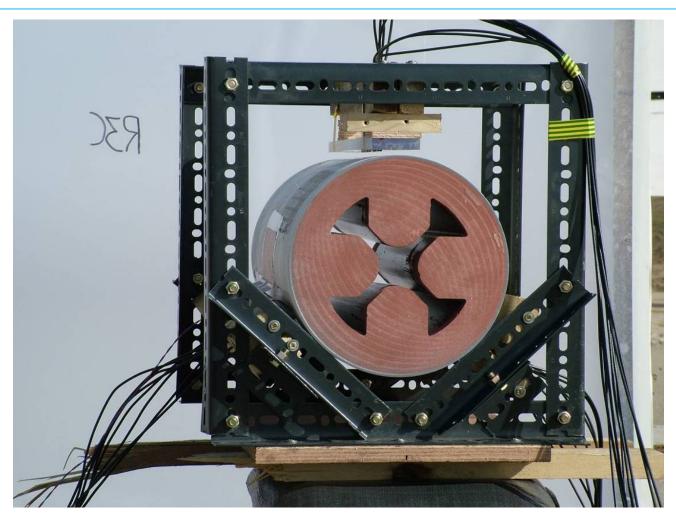
05 Experimental Set-up (2)



View from camera direction showing:

- Rocket motor section,
- Diffusing background,
- White backboard,
- Sabot traps
- Blast gauge positions.

05 Close-up of Rocket Motor Section Prior to Firing

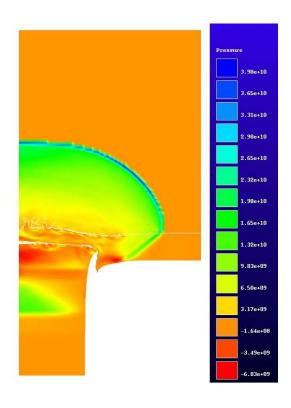


The motor section is shown in a cage which allowed the time-of-arrival probes to be spaced off from the motor casing.

A make foil can be seen attached to the left surface of the motor section.

The round number can be seen marked on the diffusing screen behind the cage.

06 Experiments on Rocket Motor Sections



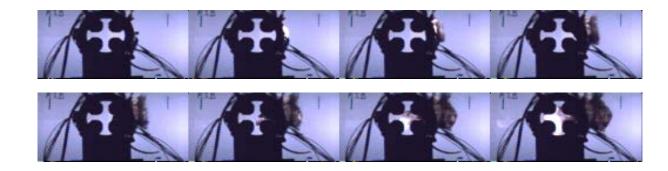
06 STANAG FSP at 1890m/s on Rocket Motor Section

Impact occurs in the second frame of the Phantom high-speed video record.

The FSP caused an ignition on impact and a larger burning reaction in the bore after ca. 80µs.

The propellant burnt out and the casing remained intact.







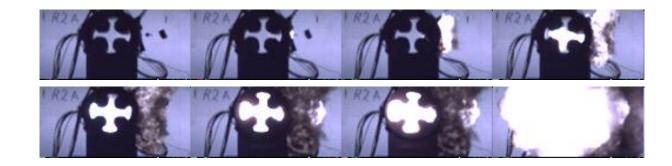
06 STANAG FSP at 2584m/s on Rocket Motor Section

The Phantom highspeed video record shows the projectile impacting in the second frame.

As in the previous test the FSP caused an ignition on impact and a larger burning reaction in the bore after ca. 40-70µs.

The result was a pressure burst with the casing split into two pieces A small amount of propellant was recovered.



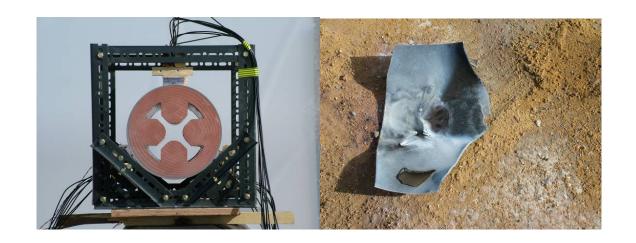


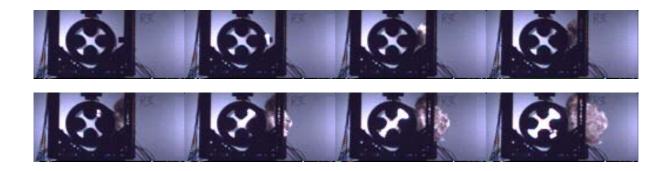


06 30mm FSP at 1743m/s on Rocket Motor Section

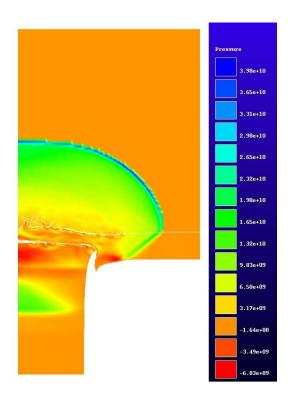
The impact occurs in the second frame and is through the thick portion of the propellant grain.

The result was a violent pressure burst generating the highest blast pressure of any of the tests on motor sections (25.3 kPa @ 5m).





07
Experiments on Complete
Rocket Motors



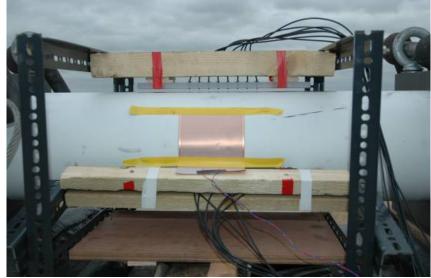


07 Experiments on Complete Rocket Motors

We have carried out two tests on complete motors, both with the STANAG projectile. The intention being to test at the higher (2530m/s) & the lower (1830m/s) stipulated velocities.

The set-up for the 1st test at the higher velocity is shown below. The motor is clamped and tied to several 1.5 ton reinforced concrete blocks.





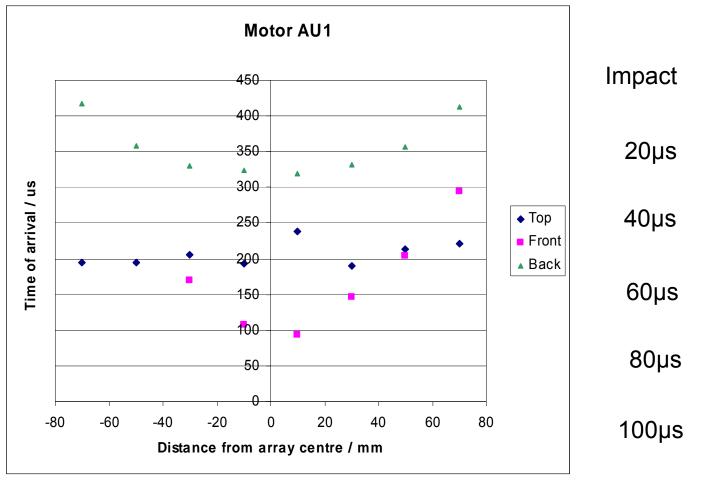
07 Results of STANAG Test at 2434m/s

The rocket motor was arranged such that the thin wall of the propellant grain was in the shot line.

The motor burst, splitting into three parts, and then burnt out.



07 High Speed Video & Time of Arrival Gauges for Motor STANAG Test at 2434m/s





07 Results of Motor STANAG Test at 1828m/s

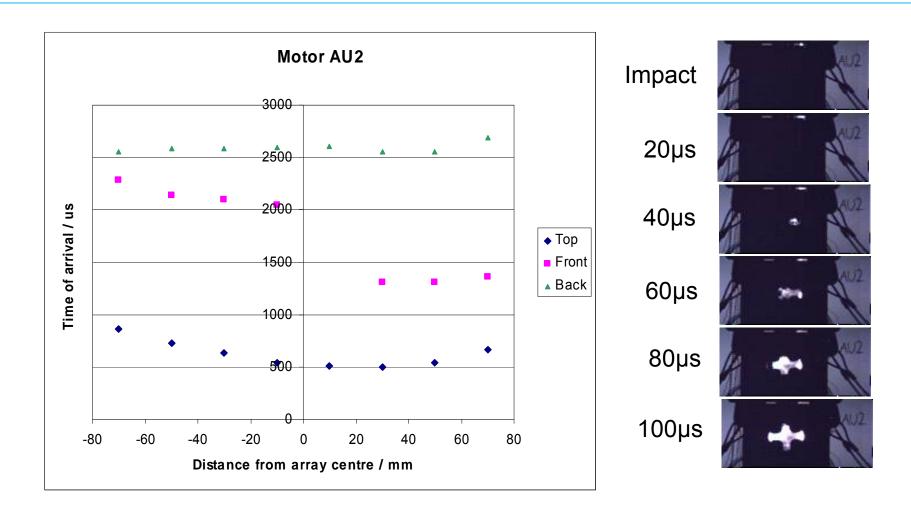
The projectile caused the motor to ignite and then rapidly overpressure blowing out the upper central section of the motor.

The remaining parts of the motor burnt out completely and with significant thrust.



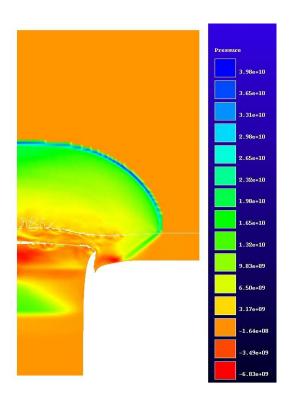


07 High Speed Video & Time of Arrival Gauges for Motor STANAG Test at 1828m/s





08 **Discussion & Conclusions**





08 Discussion & Conclusions (1)

Tests were carried out on a total of 14 motor sections and 2 All-Up motors.

- •Responses ranged from Type 1 to Type 2/3 depending on the fragment type and velocity employed.
- •As might be expected there was a general trend towards increased violence as both the velocity and mass of the fragment were increased.
- •Vigorous burning reactions were usually observed in the damaged bore section of the motors, and in a detonable propellant it is likely that many of these reactions would have progressed to detonation through and XDT mechanism.
- •The increased confinement offered by a complete motor, compared with a section, gave rise to a more violent event under the lower velocity STANAG test condition.
- •The blast gauges and time-of arrival probes have yielded valuable data which it is hoped to use for testing and validation of future modelling studies.



08 Discussion & Conclusions (2)

Orientation of the propellant grain with respect to the shot line appeared to influence the violence of the response.

- •For the STANAG projectile the most violent reactions were observed when the thin part of the propellant grain was along the shot line.
- •In the case of the 20mm projectile similar events were observed in both orientations.
- •Only two firings were carried out using the 30mm FSP but they suggested that more violent events may be expected when firing through the thicker portion of the propellant grain. This projectile gave the most violent reactions from any of the sections, presumably as the result of increased damage to the propellant grain by the heavier fragment.

The use of motor sections enables a larger, more statistically significant, number of tests to be carried out and aids the use of diagnostics in determining response mechanisms. However, the additional confinement offered by complete motors can lead to differences in response violence and this needs to be considered when carrying out a hazard assessment.



QinetiQ



Pierre Pelletier, Nathalie Maher: GD-OTS Canada

Patrick Brousseau: DRDC-Valcartier Alberto Carillo: BAE Systems OSI;

Charlie Patel: PM CAS

Bernard Mahé: Eurenco France

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Presentation Outline



- Background
- > Studied formulation and variations
- Processing studies
- NOL LSGT tests
- Summary and Future work



Background



- > IM enhanced 120mm mortar cartridge
 - Development program of an IM enhanced 120mm mortar ammunition by a team led by GD-OTS Canada started in 2001.
 - Main charge explosive: HBU88B cast-cure formulation based on I-RDX®
 - Type IV reaction for all IM tests (fuze and adapter more than 15 meters)
 - Cartridge qualification under M932A2 in 2006
- ➤ Recrystallized I-RDX® from Bachman RDX showed to loose its properties over time (Spyckerelle et al. studies)
- > Goal: Study of the link between NOL LSGT test and IM tests
- Phase 1: formulation processing work and LSGT tests of HBU88B produced with two versions of premixes of RDX produced by BAE OSI HSAAP.

Studied formulation and variations



> HBU88B formulation

- Formulation originally developed by Eurenco France
- 88% I-RDX®
- 12% binder based on Hydroxyl Terminated Polybutadiene (HTPB)
 prepolymer cured with Isophorone di-isocyanate (IPDI) containing Di-Octyl Adipate (DOA) plasticizer.
- ➤ Modified formulations studied: Replacement of I-RDX®
 - BAE OSI HSAAP proprietary mix of RDX (OSXP-1)
 - Mix of standard materials premixes (CXM-7/CXM-AF-1)
 - CXM-7: Premix of RDX in DOA used for PBXN-109 (Coarse particles)
 - CXM-AF-1: Premix containing fine FEM RDX in DOA used by USAF (Fine particles)

Processing method

Bi-component method developed by Eurenco France

Processing studies



> Viscosities and curing properties

Same optimal ratios of coarse (CXM-7) to fine particles (CXM-AF-1) as

for the I-RDX®

Properties	I-RDX [®]	OSXP-1	CXM-7 / CXM-AF-1
EOM viscosity (component A) (kP)	5.0 – 10.0	9.1	11.0
EOM viscosity (HBU88B) (kP)	3.0 - 7.0	2.0	5.2
Pot life (min)	25	35	25
Curing time (hr)	24	24	24

> Material properties

Properties	Specification	I-RDX [®] (qualification)	OSXP-1	CXM-7 / CXM-AF-1
% RDX*	$87.0 \le \le 89.0$	88.1 ± 0.5	88.9 ± 0.1	88.1 ± 0.7
Hardness (shore A)	$60 \le \le 95$	66 ± 3	72 ± 0.2	74 ± 2
Density (g/cc)	$1.60 \le \le 1.65$	1.62 ± 0.005	1.61 ± 0.001	1.61 ± 0.001
S _m (MPa)	≥ 0.6	0.87 ± 0.05	0.70 ± 0.02	0.96 ± 0.03
e _m (%)	≥ 4	8 ± 3	10 ± 0.1	18 ±3
VST (cc/g)	≤ 0.5	0.11 ± 0.04	0.03 ± 0.01	0.04 ± 0.01

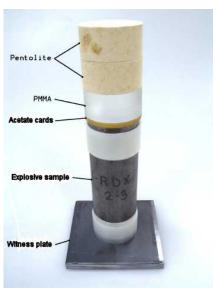
* This includes both the RDX and HMX for the BAE OSI HSAAP material.



> Set-up

- Similar to NOL Large Scale Gap TEST
 - RP-502 detonator
 - Views of the set-up and DRDC Valcartier detonation bay











➤ Data for comparison – 50% detonation point

Composition B

Measured value: 216 cards

Literature value: 209 cards





215 cards - GO



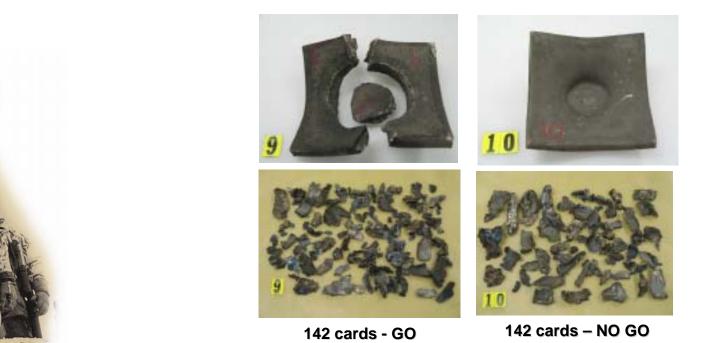


217 cards - NO GO



➤ Data for comparison – 50% detonation point

- PBXN-109
 - Measured value: 142 cards
 - Literature value: 134 200 cards (Beyard, M., Variations of PBXN-109 sensitivity, NIMIC/AC-326 RS-RDX technical meeting 2003 – MSIAC Gap tests database)



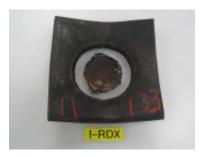
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- ➤ Data for comparison 50% detonation point
 - HBU88B (I-RDX)

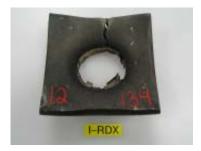
• Measured value: 133.5 cards

• ARDEC values: 141.5 – 143 cards





133 cards - GO



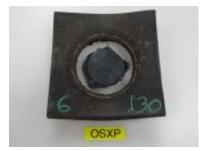


134 cards - NO GO



➤ Data – 50% detonation point

- HBU88B (OSXP-1)
 - Measured value: 131 cards











131 cards - NO GO (?)

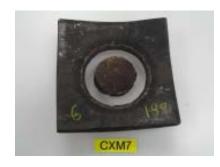




132 cards - NO GO



- ➤ Data 50% detonation point
 - HBU88B (CXM-7/CXM-AF-1)
 - Measured value: 149.5 cards





149 cards - GO





150 cards - NO GO



Summary and future work



- Processing of two HBU88B formulations with CONUS RDX
 - Properties in the same range as HBU88B with I-RDX® except for lower end-of-mix viscosity for OSP-1 formulation and higher mechanical properties for CXM mixes.
- ➤ Validation DRDC-V LSGT equipment: results in the same range as those obtained in the literature for standard explosives (Composition B and PBXN-109).
- ➤ HBU88B produced with CONUS RDX gives NOL LSGT results in the same range as HBU88B made with Eurenco I-RDX:
 - I-RDX: 133.5 cards (ARDEC: 142 cards same range)
 - OSXP-1: 131 cards
 - CXM-7/CXM-AF-1: 149.5 cards (More sensitive)
- Phase 2: IM test results to be presented by PM CAS organization (CLIMEx program)



Qualification Of ITEX-07 Explosive For Fuze Applications

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BAE Systems

1

PBXN-7 / ITEX-07



PBXN-7 Composition

•	RDX	35 %
•	TATB	60 %
•	Copolymer (VITON A)	5 %

- Specification MIL-DTL-82874B
- Qualified by the US-Navy
- "PBXN-7" manufactured with OSI-TATB, evaluated by the US Navy, has enhanced shock insensitiveness
- To describe its improved IM property, this variant of PBXN-7 for future military use has been designated ITEX-07

Qualification – Time Schedule



DynITEC

- Physical tests and thermal characteristics (related to detonating devices)
- Finished Jan 08
- Additional tube tests in summer 08

WIWEB

- Tests according to STANAG 4170 / TL 1376-0800 / AOP-7
- Sep 08 Jan 09
- Contracted by DynITEC

QinetiQ

- EMTAP-Tests (No 35, No 41, No 42)
- Expected in May 09

Schutzvermerk nach ISO 16016 beachten

Friction / Impact

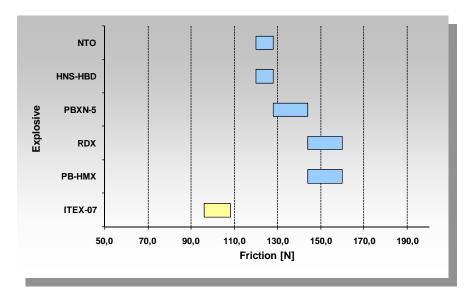


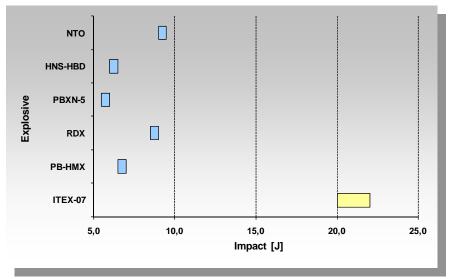
	Friction		Impact	
Explosive	No-Go [N]	Go [N]	No-Go [J]	Go [J]
ITEX-07	96	108	20,0	22,0
РВ-НМХ	144	160	6,5	7,0
RDX	144	160	8,5	9,0
PBXN-5	128	144	5,5	6,0
HNS-HBD	120	128	6,0	6,5
NTO	120	128	9,0	9,5

Test set-ups and procedures according to BAM Determination of no-go-level:

Highest level with no reaction or no detonation in 6 tests.

AOP-7 min. requirements for booster explosives 80 N for friction and 3 J for impact





4

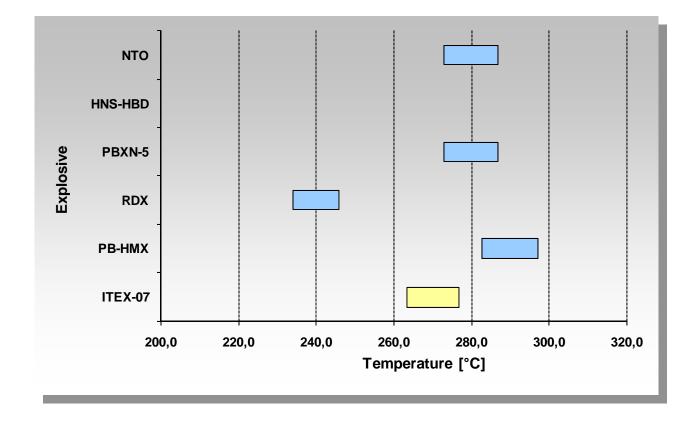
Ignition Temperature



Explosive	Temperature [°C]
ITEX-07	270
PB-HMX	290
RDX	240
PBXN-5	280
HNS-HBD	> 310
NTO	280

Wood's Metal Bath Test in accordance with DynITEC-procedure 3010

AOP-7 min. requirements for booster explosives > 180°C at 5°C/min

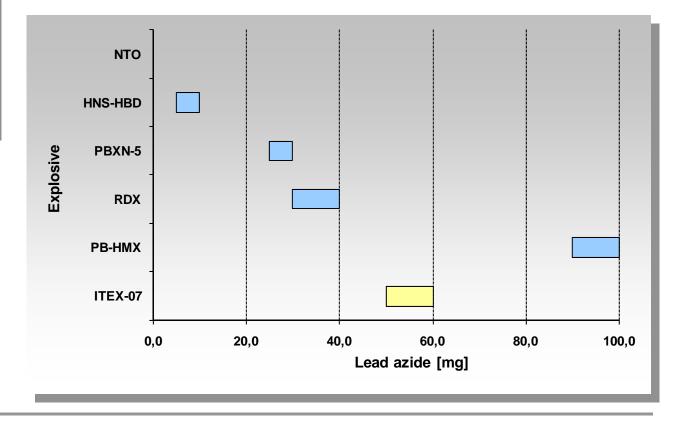


Minimum Priming Charge Test



Explosive	No-Go [mg]	Go [mg]
ITEX-07	50	60
РВ-НМХ	90	100
RDX	30	40
PBXN-5	25	30
HNS-HBD	5	10
NTO	>110	

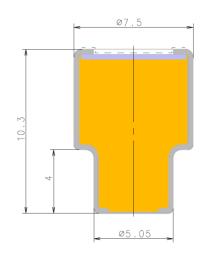
- Special DynITEC-method to evaluate explosives for use in detonating devices
- Determination of the minimum amount of primary explosive to get a reliable initiation of the (secondary) explosive under investigation
- Primary explosive (lead azide 94oD) is changed in 5mg-intervals



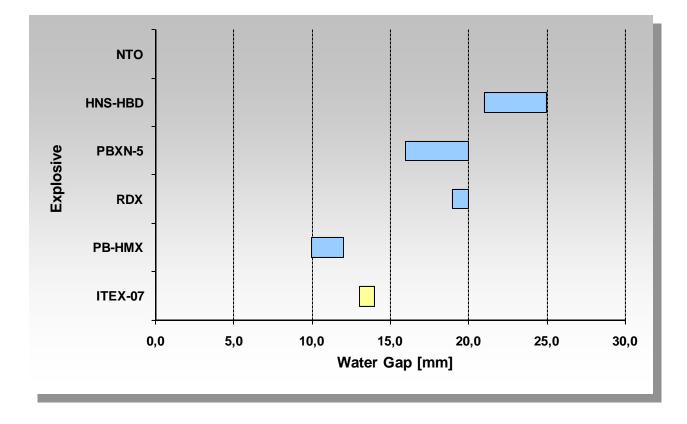
Booster-Gap-Test



Explosive	Go [mm]	No-Go [mm]
ITEX-07	13	14
PB-HMX	10	12
RDX	19	20
PBXN-5	16	20
HNS-HBD	21	25
NTO		< 5



- Test based on STANAG 4363 and AOP-21
- Designed for explosive components (boosters and leads)
- Acceptance criteria for boosters < 28mm water gap



Booster DM 1291; Loading pressure: 0,7 kbar

7

Tube Test – Electrically Heated Slow Heating (EMTAP No 42)



EMTAP Test 42











Test results

- Heating rate 1 K/min Reaction time 2:49 [h:m]
- Reaction temperature ca. 195°C
- Six fragments
 Reaction type: Cat 2

 Deflagration

Tube Test – Fast Heating (EMTAP No 41)



Test results

- Reaction after 339 s
- Two fragments
 Reaction type: Cat 2
- Comparable to Rowanex 3601





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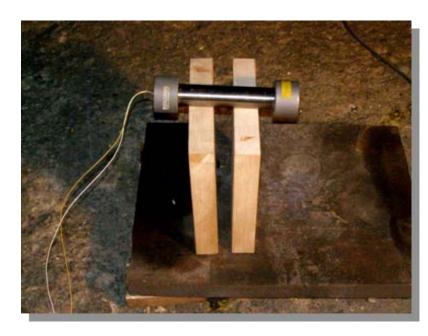
Tube Test – Internal Ignition (EMTAP No 35)



Test results

- No fragments
 Reaction type: Cat 1
- Comparable to Rowanex 3601





Schutzvermerk nach ISO 16016 beachten

WIWEB Test Results



Characteristic	Doc. (STANAG)	Test	Criteria for booster explosives (AOP-7)	WIWEB	DynITEC
STANAG 4170					
Vacuum Stability	4556	Gas liberation	< 1.0 ml/g at 100°C for 40 h	J.	24 h: 100°C: 0.04 ml/2.5g 150°C: 2.5 ml/2.5g
Thermal Characterisation	4515	DSC or	Decomposition exotherm peak: > 180°C at a heating rate of 5°C/min	> 180°C	233.8°C
		TGA		ok	ok
Ignition Temperature	4491	Wood's Metal Bath	> 180°C at a heating rate of 5°C/min	231°C	(270°C)
Electrostatic Sensitivity	4490	Small-scale spark test	National	> 32 J	./.
Impact Sensitivity	4489	BAM-Test	3 J: No reaction (10 out of 10 trials)	7,5 J	20 J
Friction Sensitivity	4487	BAM-Test	80 N: No reaction (10 out of 10 trials)	80 N	96 N
Detonation Velocity	AOP-7			≈ 7690 m/s	./.
Variation of properties with age	AOP-7			ok (4 weeks / 80°C)	J.
Explosive response when ignited	4491	see EMTAP-tests			
TL 1376-0800			Criteria for insensitive explosives		
Heating		Fast Cook Off (90 K/min)	Reaction type 5 (burn)	Type 5	
Impact		Caliber 12.7 mm vo = 900 m/s Distance = 6 m	Reaction type 5 (burn)	Туре 6	
Shock		Gap test Diameter: 21 mm	No detonation ≤ 15 mm	to be determined	
EMTAP (Tube Tests)					
Internal Ignition	No 35		Reaction category <= 2	1 Test pe	rformed: Cat 1
Fast Heating	No 41		Reaction category <= 2		rformed: Cat 2
Electrically Heated	No 42		Reaction category <= 2	•	rformed: Cat 2

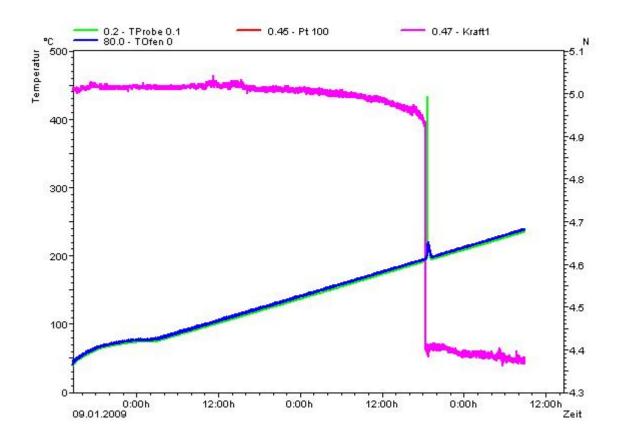
Summary



- ITEX-07 is qualified according to STANAG 4170.
- Preliminary EMTAP-tests show excellent IM-properties less than or equal to deflagration Cat 2 reaction.
- Thermal behaviour is dominated by RDX: separate investigation & report.
- Material used for the insensitive booster of the new UK multi-purpose artillery fuze L166A1 (production starts in summer 2009).
- ITEX-07 is currently being allocated an EX-number by the US DoD.

Thermal Stability (heating ramp)



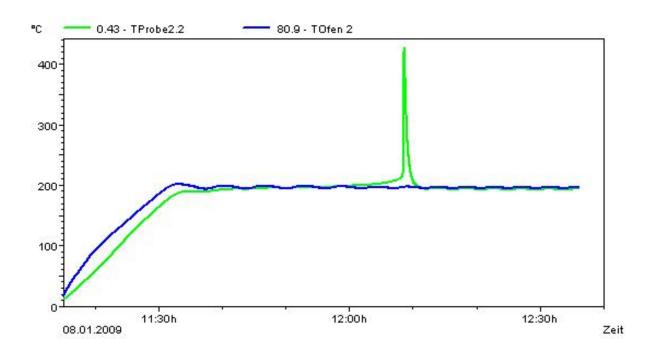


Heating rate: 3 K/h

Sample volume: 8 cm³ cube

Thermal Stability (isoperibolic)





T_{isoperibolic}: 195 °C

Sample volume: 1,7 cm³ cube

Volume-dependent self-ignition temperatures for ITEX-07



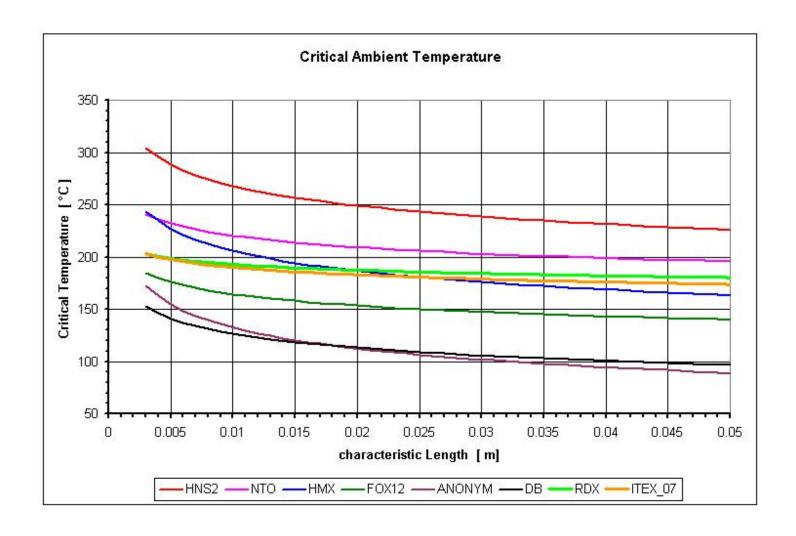
Volume	SIT _{exp}	T_U _{krit.,theoret} .
0,2 cm ³ L=0,003 m	203 °C	203 °C
1,0 cm3 L=0,005 m	197 °C	197 °C
1,7 cm ³ L=0,006 m	194 °C	195 °C
8 cm ³ L=0,01 m	190 °C	190 °C

SIT_{exp}: Self-ignition temperature determined by experiment

 $T_{-}U_{krit.,theoret.:}$ Self-ignition temperature according to the thermal explosion theory

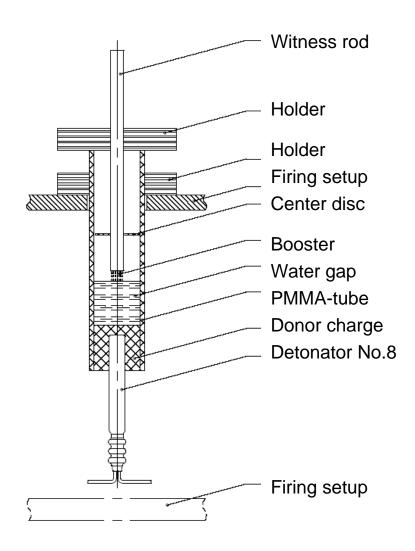
Volume-dependent self-ignition temperatures (acc. to thermal explosion theory)

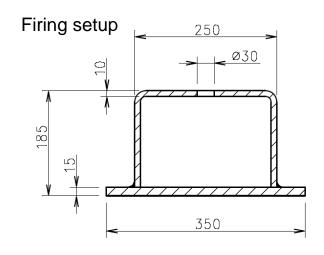


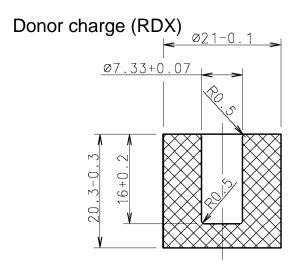


Booster-Gap-Test: Experimental Setup







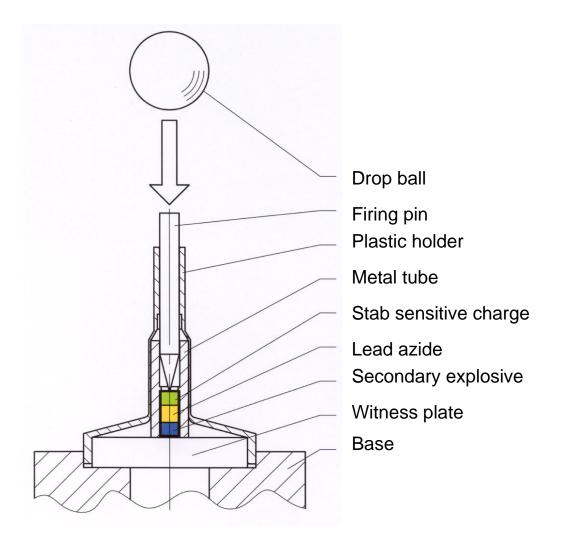


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Minimum Priming Charge Test



- Special DynITEC method to evaluate explosives for use in detonating devices
- Determination of the minimum amount of primary explosive to get a reliable initiation of the (secondary) explosive under investigation
- Primary explosive (lead azide 94oD) is changed in 5mgintervalls



Schutzvermerk nach ISO 16016 beachten



Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination Project (RIGHTTRAC Project)

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2009 IMEMTS, Tucson, AZ, 13 May 2009







Acknowlegments

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- I. Poulin
- M. Beauchemin

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- The team at the Biotechnology Research Institute (NRC Canada)
- The team at INRS-ETE
- The CRIQ
- DND/Director General Environment for funding



Outline

- RIGHTTRAC Objective and Concept
- Background
- Current Work
- Summary



RIGHTTRAC

- Technology Demonstration Project
 - 5 years
- Objective: To demonstrate
 - that green and IM munitions have better properties than current munitions.
 - that it is feasible to implement a solution that would ease the environmental pressures on the Canadian Forces ranges and training areas.



RIGHTTRAC Concept

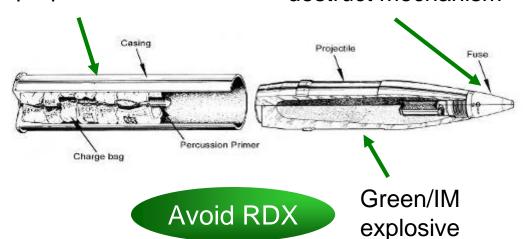
- Test vehicle: 105-mm M1 artillery round
 - Scalable to other weapons

Decrease the production of UXOs

Avoid using toxic and carcinogenic ingredients in gun propellants

Green/IM propellant

More reliable fuzing system with self destruct mechanism



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Important Considerations

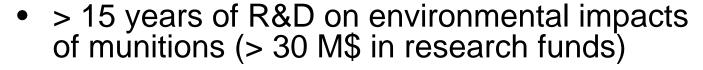
- Military readiness is imperative
- Most munitions fired in training areas
 - Around 95% before Afghanistan
- Increased personnel in Land Forces
- Increased foreign training



Prevention is essential to keep our (rather large) ranges and training areas in operational conditions



RIGHTTRAC Background





- Guidelines at http://www.em-guidelines.org/
- Complex environmental fate of explosives
- Mechanisms involved in the contamination
- Large international efforts with USA, Sweden, the Netherlands, U.K. and Australia





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Background – Reduce the UXOs

- Probable sources of munitions residues in target areas
 - Low-order detonations of various ordnance items
 - UXO blow-in-place operations (BIPs)
 - Corrosion of surface and subsurface UXO
 - Rupture of UXO items from nearby detonations



Environmental Impacts





Safety Hazards





Background – Reduce the UXOs

- 81-mm mortar cracked by the detonation of another incoming round
- One round can potentially contaminate a large amount of underground water in one rain season

Cracked shell

Production

Result











Background – Replace Gun Propellant Ingredients

- Significant amounts of propellant residues were detected at firing positions
 - Incomplete combustion of propellants
 - Open burning of excess propellant
- Some constituents may be toxic or carcinogenic
 - DNT, NG, phtalate derivatives, heavy metals, etc.









Background – Avoid RDX





- One of the explosives that is used the most
- The most mobile through the soil profile
- Migrates to groundwater and contaminates surrounding areas
- It is considered rather toxic
- Our solution: HMX
 - Performs better than RDX (more expensive)
 - Almost a drop-in replacement in many applications







Background – Avoid RDX

Water solubility (mg/L)		
RDX	HMX	
42	5.0	

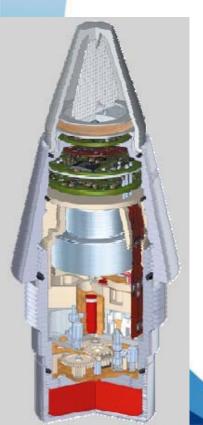
EPA Lifetime Health Advisory for Drinking Water (μg/L)		
RDX	HMX	
2	400	

- HMX is less soluble than RDX
- HMX is less toxic than RDX
- Factor of 1000!
- Other energetic solids could also be appropriate but at this point in time, HMX is our best bet!

http://www.clu-in.org/char/technologies/exp.cfm http://www.epa.gov/waterscience/criteria/drinking/dwstandards.pdf



- Fuze
 - Development of a self-destruct capability to current artillery fuzing systems in case of a failure of the primary fuze
 - operator handling
 - soft impacts
 - age-related failures
 - Implementation in an existing fuze
 - Reduce the actual live fire dud rate from approximately 1-5% overall to less than 1%









- "Green" M1 propellant
 (DNT, DBP and DPA free)
 Green compliance = High; IM compliance = Low
- Modified triple base propellant
 Green compliance = High; IM compliance = High
- Modified HELOVA
 (HMX-based propellant with ETPE (Energetic ThermoPlastic Elastomer) and energetic plasticizer)

 Green compliance = Medium; IM compliance = Very High
- Propellant combining nitrocellulose and ETPE
 Green compliance = High; IM compliance = Very High







Performance of the gun propellants

	Relative Force
Current M1 gun propellant	100
"Green" M1 propellant (DNT, DBP and DPA free)	112
Modified triple-base propellant	109
Modified HELOVA (HMX-based propellant with ETPE)	138
Propellant combining nitrocellulose and ETPE	81



- Explosive charge
 - Option 1. Green/IM Explosive (GIM)
 - Mix of melt-cast explosives with an Energetic Thermoplastic Elastomer (ETPE) patented by DRDC Valcartier
 - TNT/HMX/ETPE
 - Conventional melt-cast apparatus can be used without modifications
 - Recyclable products for remilitarization
 - Option 2. Plastic-Bonded Explosive (HMX-based)
 - High mechanical strength, good explosive properties, excellent chemical stability, insensitivity



Performance of the explosives





	Comp. B	GIM	PBX
		(TNT/HMX/ETPE)	(HMX/HTPB/DOA)
Density	1.69	1.69	1.62
(g/cm3)			
VoD	7885	7708	8197
(m/s)			
$P_{CJ} = \frac{1}{4} \rho D^2$	26.3	25.1	27.2
(GPa)			
Plate dent	0.782	0.799	-
(cm)			



NOL Large Scale Gap Test

Comp. B216 cards

– GIM (TNT/HMX/ETPE)182-184 cards

DREV Gap Test

- Comp. B 1.14 cm

– PBX (HMX/HTPB/DOA)0.79 cm





RIGHTTRAC - IM Tests

- Bullet Impact on 105mm M1 projectiles
 - GIM (TNT/HMX/ETPE)
 - Burning and No reaction
 - PBX (HMX/HTPB/DOA)
 - Burning reaction



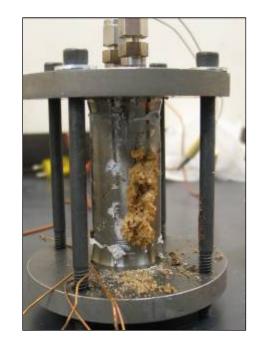


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RIGHTTRAC - Small-Scale IM Tests

- Variable Confinement Cook-off Test (VCCT)
 - GIM (TNT/HMX/ETPE)
 - Deflagration and overpressure reactions
 - 183 °C
 - PBX (HMX/HTPB/DOA)
 - Overpressure
 - 203-207 °C









Toxicity studies (BRI-NRC)

- Formulations under study: GIM, PBX, gun propellants (2), reference formulations (M1 propellant and Comp B)
- Solubility and dissolution kinetics
- Abiotic degradability in water and in soil
- Transformation of DPA and NQ
- Transport in batch soil assays and in soil columns
- Ecotoxicity assays
 - Effects of the above munitions formulations, their individual components and the reference compounds in soil and sediment
- Bioavailability
 - For selected soil organisms receptors using chemical (extracts), toxicological (toxicity tests) in different soil conditions







Conclusions

- We are trying to demonstrate that green and IM munitions have better properties
- We are trying to ease the environmental pressures on the Canadian Forces ranges and training areas
- Our demonstrator is an artillery 105-mm round
- We are working on:
 - the fuze (to reach a near-zero dud rate)
 - the gun propellant (to eliminate potentially toxic components and incorporate IM ingredients)
 - the explosive (to replace RDX move to HMX, add a binder to reduce bioavailability and make it IM)
- Not many projects integrate both IM and green characteristics

DEFENCE DÉFENSE







TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Insensitive Munitions (IM) Testing:
25mm Target Practice, Discarding Sabot with Trace (TPDS-T), M910
Cartridge using ECL® Propellant







Insensitive Munitions (IM) Testing:

25mm Target Practice, Discarding Sabot with Trace (TPDS-T), M910 Cartridge using ECL® Propellant

Presented by:

Mica Mc Ghee-Bey

Propulsion Manufacturing Technology & Producibility Branch Energetics Producibility & Manufacturing Technology Division RDECOM-ARDEC, Picatinny Arsenal, NJ

2009 Insensitive Munitions and Energetic Materials Technology Symposium Tucson, AZ



11 – 14 May 2009



Acknowledgment

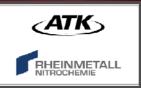


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 - Mr. Beat Vogelsanger
 - Mr. Schädeli Ulrich
 - > ATK Ammunition and Energetics
 - Ms. Kelly Brown Moran





Outline



- Overview
- System Description
- Objective
- ☐ Why ECL?
- ☐ Test Results
 - Ballistics
 - Engineering IM
- Conclusion
- Planned Effort





Overview



- ☐ The U.S. Army is increasingly stressing the necessity of Insensitive Munitions (IM) compliance to provide a more cost effective, efficient means of transporting, storing and handling munitions
- □ PEO Ammunition strategy plan adopted an IM initiative to bring medium and large caliber munitions into IM compliance
- Existing medium and large caliber munitions do not meet Insensitive Munitions (IM) requirements
- □ Develop and investigate IM technologies (<u>less sensitive propellant</u>, <u>cartridge case and ammo can venting concepts</u>) to enhance munitions survivability when subjected to extreme environments and unplanned stimuli
 - → IM improvements over the existing designs to enhance the survivability of logistical and tactical combat systems
 - **→** Does not degrade the performance of the systems
 - → Minimize injury to personnel
- □ Developed solutions will be demonstrated for IM enhancement using the 25mm APDS-T, M910 cartridge



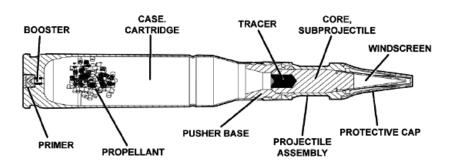


System Description



☐ The 25mm M910 Target Practice, Discarding Sabot with Trace (TPDS-T), M910 cartridge is a limited range munitions ballistically matched to the service cartridge, 25mm Armor Piercing Discarding Sabot with Tracer

(APDS-T), M791 cartridge.



Length (max)	223 mm
Weight	419 g
Projectile Mass	98.8 g
Propellant Weight	98.5 g
Muzzle Velocity	1520 m/s
Chamber Pressure @ Ambient	454 MPa
Trace Time	4.0 sec
Dispersion	0.40 x 0.40 mr

- Maximum range is less than 8000 meters
- ☐ The M910 is fired in lieu of the M791 from the M242 25mm autogun turret mounted on the M2/M3 Bradley Fighting Vehicle System during live fire gunner training and qualification





Objective



- □ Develop and investigate IM technologies to enhance munitions (System Level) survivability when subjected to extreme environments and unplanned stimuli
 - ✓ Less sensitive propellant to mitigate fragment impact deficiency



✓ Cartridge case venting





✓ Ammo can venting







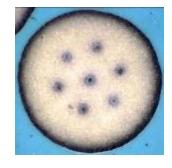


ECL® Propellant Technology for Medium Caliber Applications





- Main Benefits of new ECL® propellants compared to current nitroglycerine-base propellant solutions:
 - > Improved performance potential due to
 - ✓ High energy density and thermal conversion
 - ✓ Tunable force level, favorable thermodynamic features
 - Improved dispersion, consistency and repeatability
 - ✓ improved accuracy and precision
 - Direct incorporation of muzzle flash suppressants
 - ✓ eliminate added flash suppressant granules
 - Higher cook-off resistance
 - Less sensitve propellant Enhanced IM characteristics
 - ✓ No reaction to bullet impact
 - > NG-free (safety) / non-toxic "green" formulation
 - ✓ Avoidance of critical migration problems (plasticizers)
 - Much higher service life in A1 climatic zones due to:
 - ✓ improved chemical and ballistic stability
 - ✓ improved compatibility
 - Provides equal to or better chemical and ballistic performance and stability when compared to currently fielded NG-containing propellants



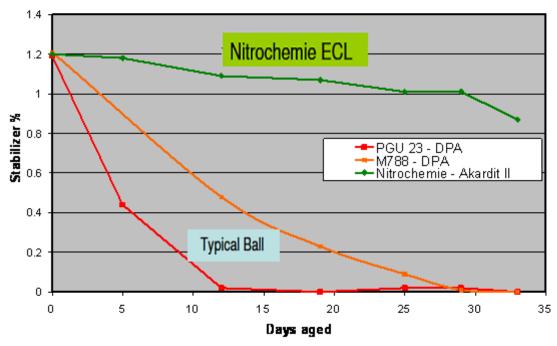




ECL® Propellant Superior Chemical Stability







- > 83% of Akardite in ECL present after 25 days at 71°C
- ➤ More than 90% of DPA in ball powder depleted after 25 days aging at 71°C

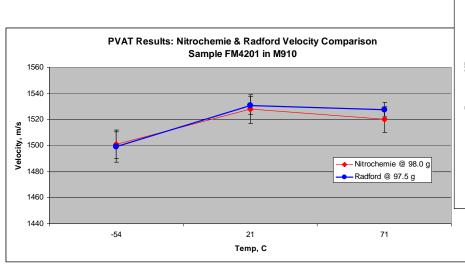


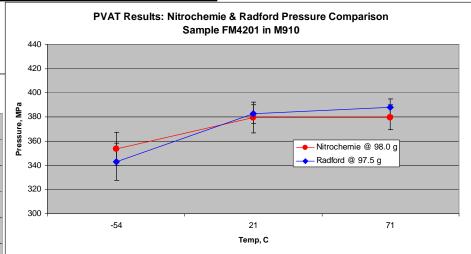


Performance Test Results



Radford Summary of Results - M910 FM4201 at 97.5 grams					
Temp, °C	Pressure, Mpa	Pres, Std Dev	Velocity, m/s	Vel, Std Dev	
-54	342.9	15.3	1498.9	11.70	
21	382.5	7.6	1530.7	6.70	
71	388.3	6.9	1527.4	5.40	
Nitrochemie Summary of Results - M910 FM4201 @ 98.0 grams					
Temp, °C	Pressure, MPa	Pres, Std Dev	Velocity, m/s	Vel, Std Dev	
-54	353.5	13.6	1501	11	
21	379.6	12.8	1528	11	
71	379.7	10.3	1520	10	









Dispersion Test Results



Dispersion (distance = 50m) ECL FM 4201



Two type of penetrations:

- Projectile
- Pusher plate



Dispersion in Target Area (50m)





Muzzle Flash Signature





18

At 21°C



At 71°C



At -54°C



Engineering IM FI Test Test Setup

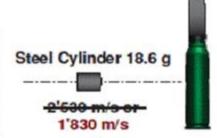


12.7 mm

Fragment Impact (STANAG 4496)

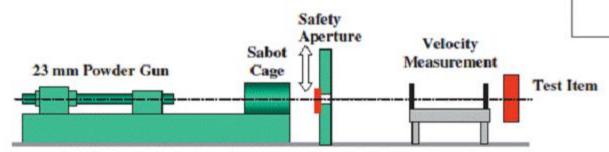
- Impact of cylindrical steel fragment at 2'530 m/s (alternatively 1'830 m/s)
- Impact normal to surface of test item
- Assessment of Reaction Type

Test available at armasuisse



15,8mm

Swiss setup uses alternative velocity (1'830 m/s)







Engineering IM FI Test Test Results







Shot 1: III Shot 2: III-IV

ECL FM 4201 in 35mm steel cartridge





Engineering IM FI Test Test Results (Cont'd)







Shot 1: III

Shot 2: III-IV

ECL FM 4201 in 35mm steel tube





Engineering IM SCO Test Test Setup



Slow Heating (STANAG 4382)

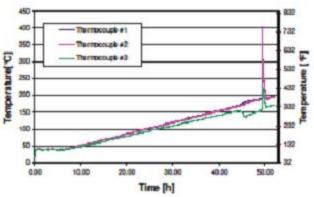
- Heating Rate: 3.3°C / h
- Assessment of Cook-Off Temperature and Reaction Type







Measured temperature during Slow Cook-off #1









Engineering IM SCO Test Test Setup (Cont'd)











Engineering IM SCO Test Test Results





Results IM engineering tests

Slow cook-off SCO, 1st run 200807, 06/17/2008 Propellant: FM 4201 in 35mm steel cartridge,

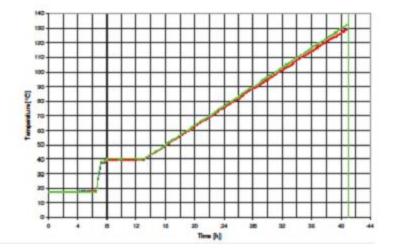


Autoignition: 130.6℃ Fragmentation: III



900 200807









Engineering IM SCO Test Test Results (Cont'd)





Results IM engineering tests

Slow cook-off SCO, 2nd run 200808, 06/19/2008 Propellant: FM 4201 in 35mm steel cartridge,

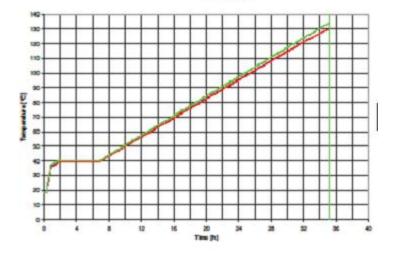


Autoignition: 131.3 ℃
Fragmentation: III



500 200808









Conclusion



□ ECL Provides:

- Enhanced IM characteristics
- Provides equal to or better chemical and ballistic performance and stability when compared to currently fielded NG-containing propellants
- Improved ballistic performance with flat tunable temperature
- Increases stability / service life





Planned Effort

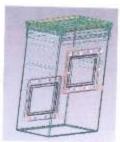


- ☐ Finalize the design of:
 - > cartridge case venting
 - ammo can (PA125) with vent windows
- □ L/A/P M910 cartridges with ECL propellant
- □ Conduct abbreviated ballistic performance tests per MIL-PRF-70775B
- ☐ Conduct full scale IM tests per MIL-STD-2105C
- ☐ Conduct abbreviated safety/environmental tests



















Quantitative evaluation of response of LOVA gun propellant charge by bullet impact and cook-off

Jun Maruyama

Ballistics and Energetics Research Section, Ground Systems Research Center, Technical Research and Development Institute, Ministry of Defense, Japan

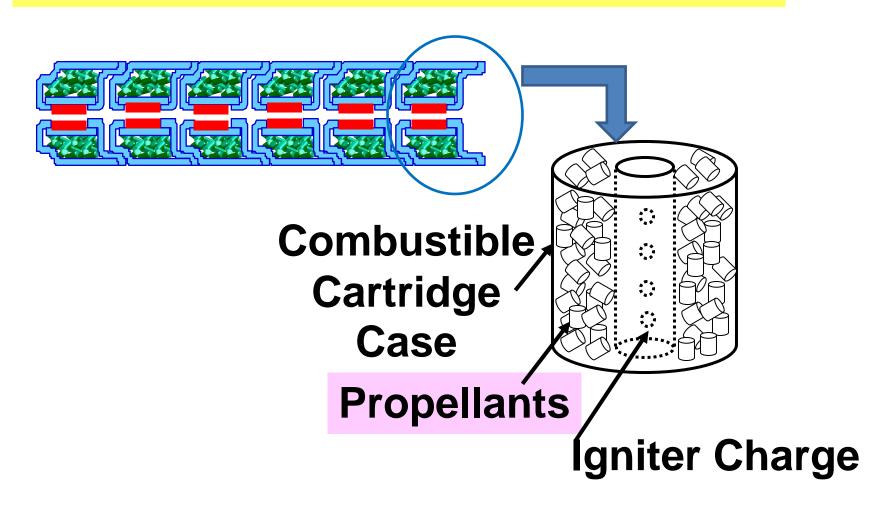
Objectives

To obtain technical data of LOVA propellant charge about the following items

1. Composition of propellant to decrease the sensitivity to bullet impact and cook-off

2. Estimation method of bullet impact and cook-off

Test Sample (Cut-view of propellant Charge)



Test Sample (Composition of propellant)

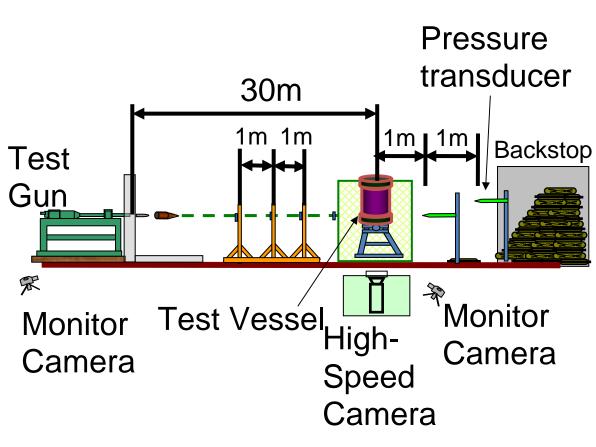
Propellants			
	Binder	Energetics	Plasticizer
Ref	NC	NQ	NG
Α	NC	RDX	DEGDN
В	NC CAB	RDX	DEGDN
С	CAN	RDX	BTTN
D	NC	RDX	BTTN
E	NC TPE	RDX	BDNPA/F

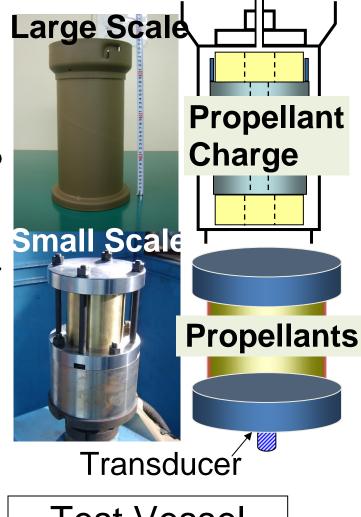
CAB Cellulose Acetate Butylate

CANCellulose Acetate Nitrate

BTTNDButane Triol Tri Nitrate TPEDThermo Plastic Elastomer BDNPA/FDBis-Di Nitro Propyl Acetal/Formal

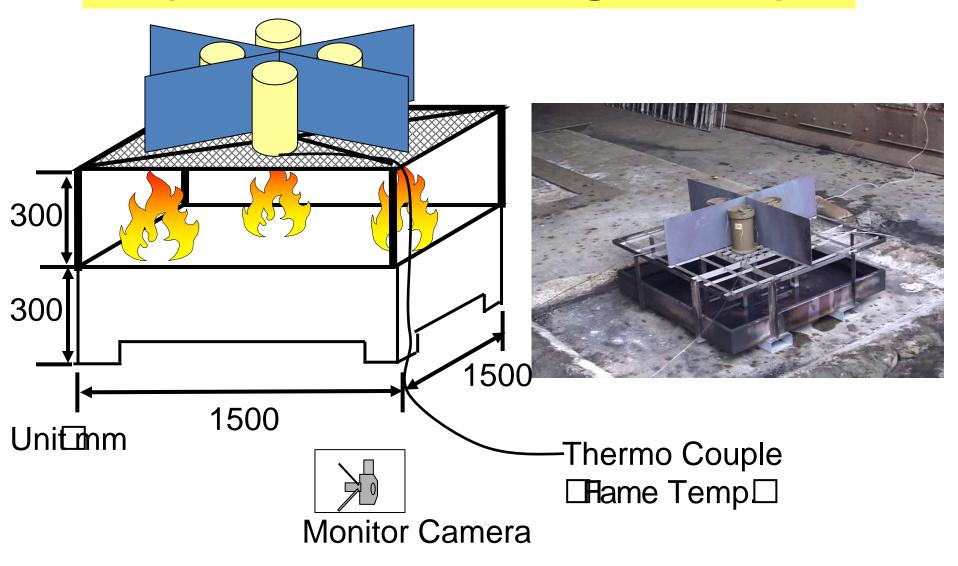
Test Setup (Bullet Impact)



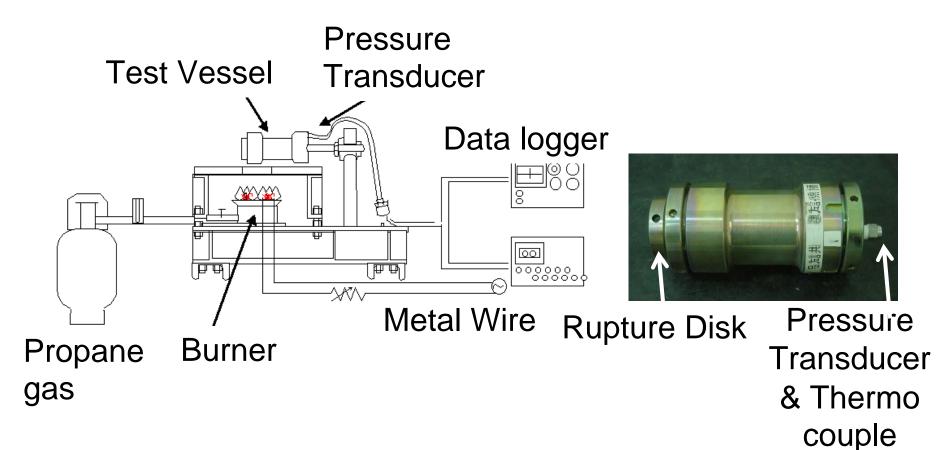


Test Vessel

Test Setup (Fast Cook-Off Large Scale)



Test Setup (Fast Cook-Off Small Scale)



Test Vessel

Cut-view of Thermal analysis and Shock sensitivity test

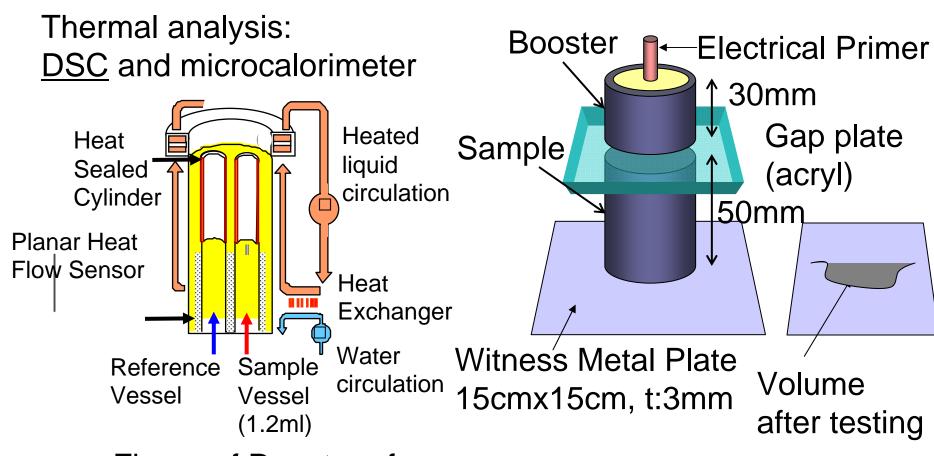
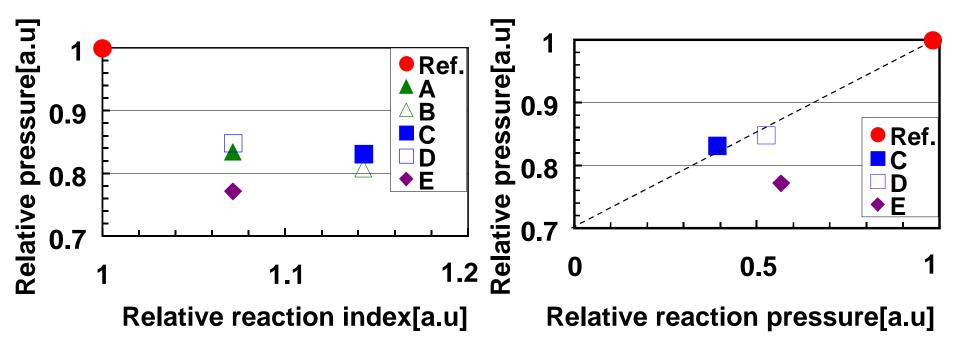


Figure of Reactor of microcalorimeter

Figure of card gap test

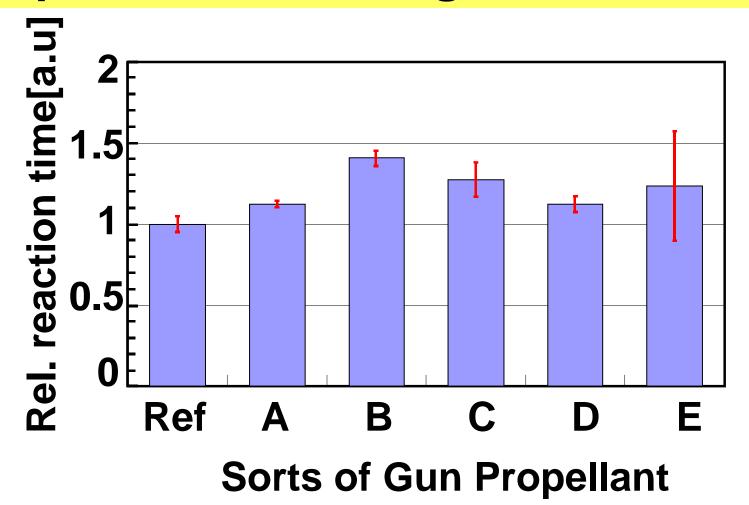
Correlation between static or reaction pressure and reaction index(MIL-STD)



* Static pressure and average reaction index of reference sample is equal to 1 as a relative value.

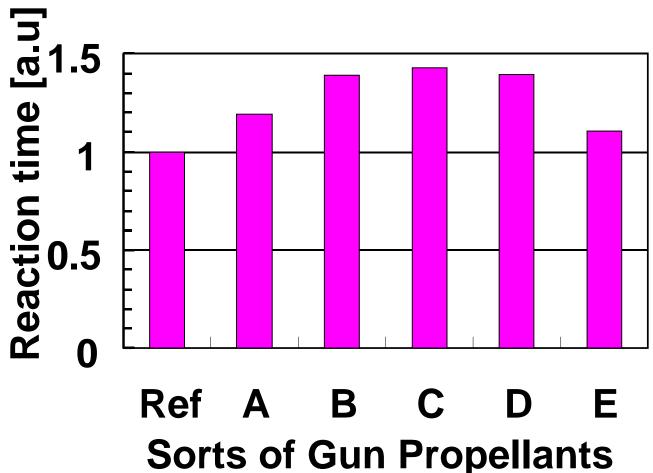
New designed props show lower static pressure than ref. Static pressure has correlation to reaction pressure.

Comparison among compositions of propellants about large scale FCO



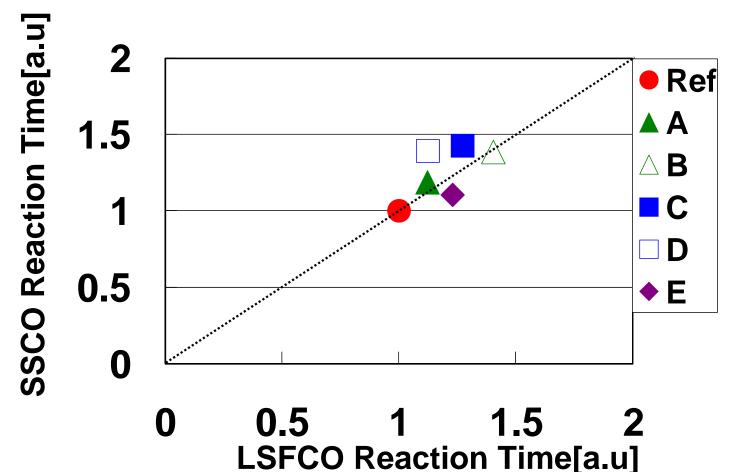
New designed props show longer reaction time than ref. B type prop takes 40% longer time to reaction than ref.

Comparison among compositions of propellants about small scale FCO



New designed props show Lower static pressure than ref. This result has same tendency as large scale FCO result.

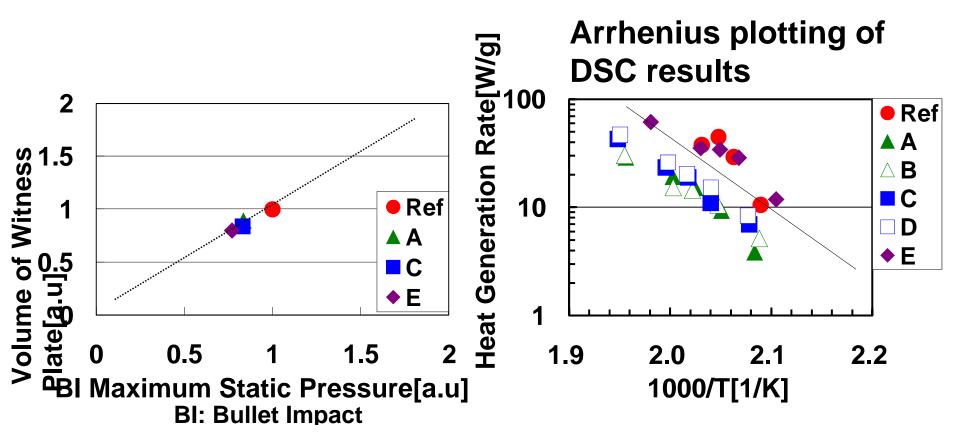
Correlation of FCO result between large scale and small scale



SSCO: Small Scale Cook Off LSFCO: Large Scale Fast Cook Off

LSFCO result shows linear correlation to SSCO result.

Comparison among compositions of propellants about BI and LSFCO



Shock sensitivity test results has correlation BI pressure
Thermal analysis results has same tendency as FCO results

→ These tests show estimation methods of BI and FCO

Conclusion

- 1. To confirm composition of propellant to decrease sensitivity to bullet impact and cook-off
- 2. To estimation method of bullet impact and cook-off by correlation data between pressure or reaction time and the card gap test and thermal analysis.

A Stable Liquid Mono-Propellant based on ADN

Eurenco Bofors, Groupe SNPE:

Per Sjöberg and Henrik Skifs Karlskoga, Sweden

ECAPS, Swedish Space Corporation Group:

Peter Thormählen and Kjell Anflo Solna, Sweden

Insensitive Munitions and Energetic Materials Technology Symposium Tucson, USA, May 11-14, 2009





Outline

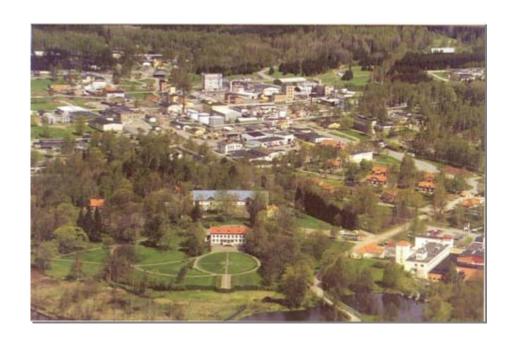
- EURENCO Bofors and ECAPS
- Properties and production of ADN
- ADN in liquid monopropellants
- High purity ADN
- Monopropellant LMP-103S:
 - Composition
 - Performance
 - Sensitivity
 - UN Transport classification
- Acknowledgements







EURENCO Bofors



High explosives and compositions

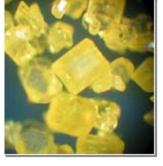


Single and multibase propellants



- Located in Karlskoga, Sweden
- 250 buildings on 744 acres of land
- Website: www.eurenco.com

New energetic molecules







ECAPS



- Located in Solna, Sweden
- Owned by Swedish Space Corporation
- Website: www.ecaps.se



Propulsion systems



Rocket engines for ADNbased monopropellant

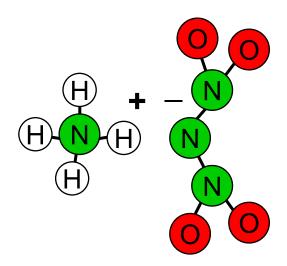




Properties of ADN

- Discovered and produced in the Soviet Union during the 1970s (not known in the west before 1993).
- Synthesised and patented in the US by SRI International in 1991.
- Research to use ADN as a solid propellant is ongoing.
- An energetic material and oxidiser.
- A salt with high solubility in water.

ADN = Ammonium DiNitramide







Production of ADN

- EURENCO Bofors is the largest producer of ADN.
- Produced from GuDN.
- ~99.6 % purity.

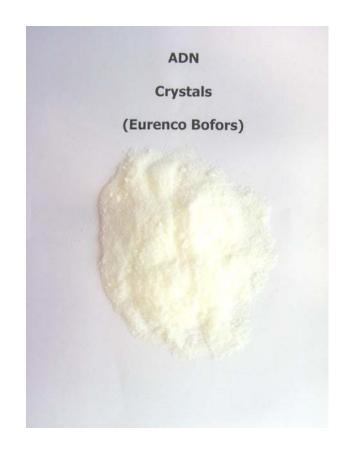
 $GuDN \rightarrow KDN \rightarrow ADN$

Gu = Guanylurea $H_2N \stackrel{\circ}{\downarrow}_{H} \stackrel{NH}{\downarrow}_{NH_2}$

$$H_2N \downarrow N \downarrow NH_2$$

K = Potassium

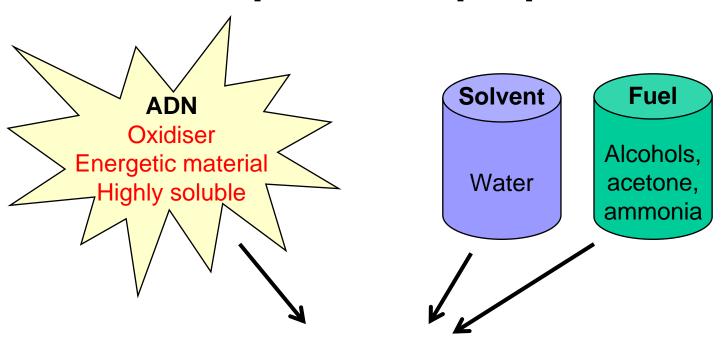
A = Ammonium







ADN in liquid monopropellants



Invented in 1997 by the Swedish Space Corporation (SSC) and the Swedish Defence Research Agency (FOI).

Liquid mono-Propellant

(a pre-mixed bipropellant)

Careful selection of solvent and fuels makes the ADNsolution much less sensitive than pure (solid) ADN.



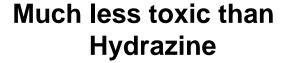


Benefits of ADN-based monopropellants

Higher performance than monopropellant Hydrazine

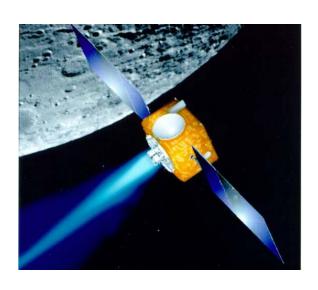
Û

Extended mission or reduced tank volume



Ú

Reduced fuelling cost









High purity ADN

- Space applications require high purity propellants, i.e., > 99.999 % purity * ("standard" ADN is ~99.6 %).
- An ADN purification process has been developed by EURENCO Bofors and ECAPS, which fulfils the high purity requirements.
- A pilot-plant-scale purification system is operational, owned by ECAPS and operated EURENCO Bofors.



* Compare with, e.g., Ultra Pure™ Hydrazine.





Monopropellant LMP-103S

Space propulsion requirements:

- Performance
- Purity
- Compatibility
- Radiation tolerance
- Storage stability
- Transport classification
- Handling safety
- Density
- Viscosity
- Vapour pressure
- Speed of sound
- Specific heat capacity
- Conductivity
- Thermal conductivity

Monopropellant LMP-103S:

ADN Methanol Ammonia Water 60-65 % 15-20 % 3-6 % balance (by weight)







Performance of LMP-103S

Compared to Hydrazine:

6 % Higher specific impulse *
&
24 % Higher density (1.24 kg/L)

①

30 % Higher density impulse

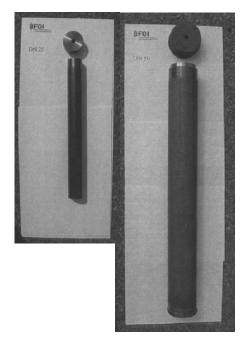
* >2300 Ns/kg demonstrated.





LMP-103S safety tests — Sensitivity

Detonation test



Large scale gap test



Critical diameter



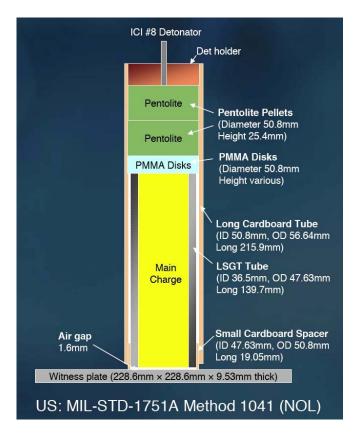
DN 25 and DN 50

Tests performed by the Swedish Defence Research Agency (FOI)

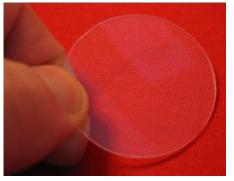




NOL Large Scale Gap Test – Setup









1 card = 0.01 inch = 0.25 mm

Substance considered to be Division 1.3 if sensitivity is less than 70 cards





Large Scale Gap Test – Water reference









Large Scale Gap Test - LMP-103S

55 cards = 0.55 inch = 14.0 mm (sensitivity of melt-casted TNT is ~150 cards)





4 negative results at 66 cards, 1 negative at 55 cards and 1 positive at 18 cards.

→ LMP-103S is considered to be an insensitive Division 1.3 substance.





Critical Diameter

Water reference

LMP-103S





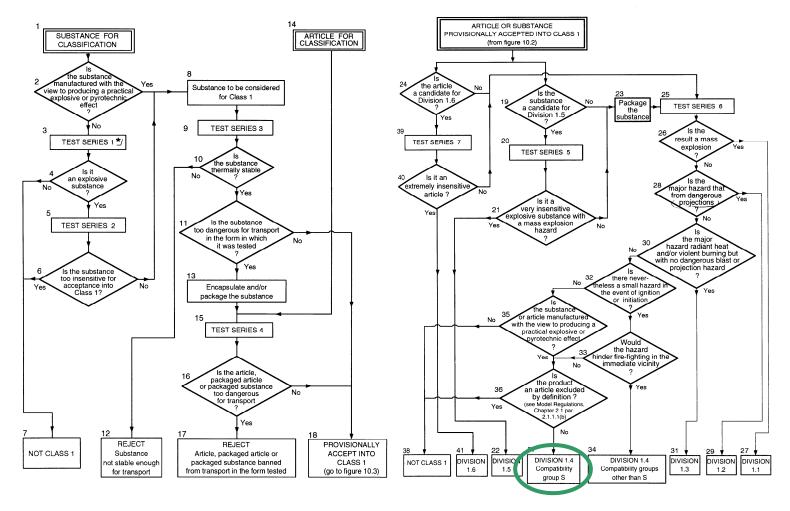


Negative results with ½" tube → Critical diameter >10 mm (inner diameter).





LMP-103S UN Transport classification



UN Class 1.4S makes airfreight possible

(in specific shipping container and following certain packaging instructions)





Summary

- High purity ADN (>99.999%) can be produced.
- Monopropellant LMP-103S fulfils space propulsion requirements.
- LMP-103S is much less toxic and has higher performance than monopropellant Hydrazine.
- LMP-103S is considered to be an insensitive Division 1.3 substance.
- LMP-103S UN transport classification 1.4S makes airfreight possible.





Acknowledgements

R&D partners:

- Swedish Space Corporation (SSC)
- Swedish Defence Research Agency (FOI)
- Edotek Ltd.
- Swerea KIMAB
- ALS Scandinavia
- Bodycote
- SafePac
- Swedish Civil Contingencies Agency (MSB)

Financial support:

- The Swedish National Space Board (SNSB)
- European Space Agency (ESA)
- Swedish Space Corporation (SSC)



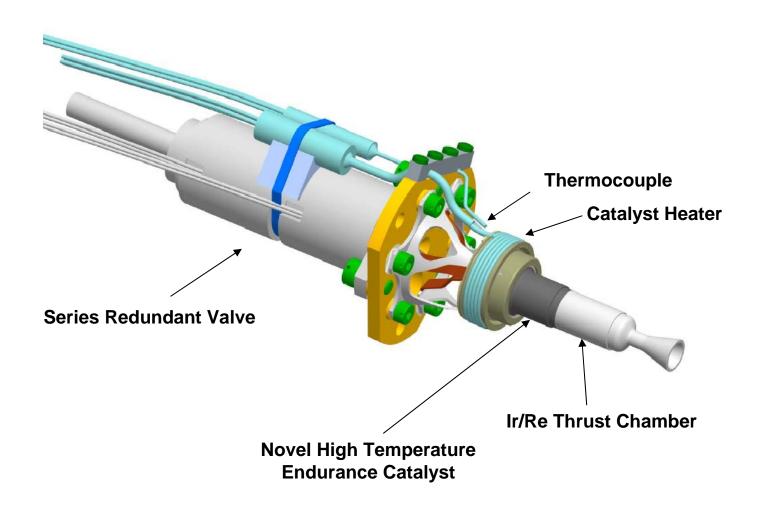


END





EM Thruster Design

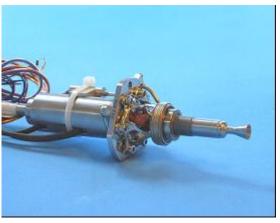




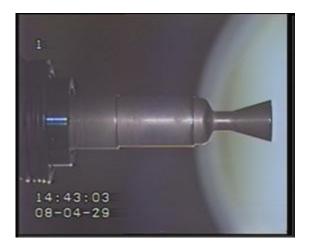


1 N HPGP Rocket Engine

1 N HPGP Rocket Engine Characteristics					
Propellant	LMP-103S				
Inlet Pressure Range	5.5 - 22 bar				
Thrust Range	0.27 - 1 N				
Isp vacuum	2010 – 2300 Ns/kg (205 - 235 sec)				
Density Impulse	2850 Ns/L				
Minimum Impulse Bit	0.01 – 0.05 Ns				
Overall Length	176 mm				
Mass	0.34 kg				
Demonstr	ated Life				
Total Impulse	50 kNs				
Pulses	60 000				
Propellant Throughput	25 kg				
Accumulated Firing Time 24 hours					
Longest Continues Firing	1.5 hours				
Stat	us				
Ready for flight o TRL					



1 N HPGP Thruster (FM)







HPGP Propulsion System Design for PRISMA

Conventional Monoprop. System Architecture

- Operation in Blow-down mode
- All Fluid Components are COTS with extensive flight heritage

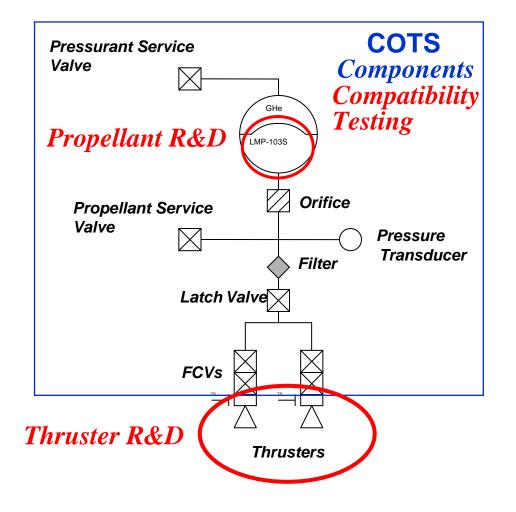
Novel Propellant and Thruster Technology

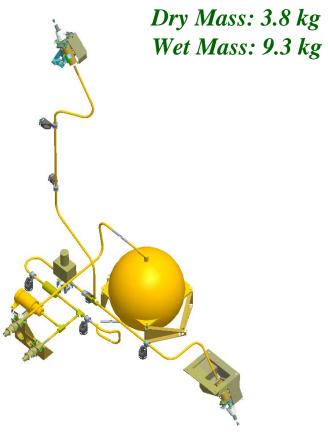
- 1 N HPGP Thrusters
- Propellant load is 5.5 kg of LMP-103S





HPGP Propulsion System Hydraulic Schematic & Lay-out



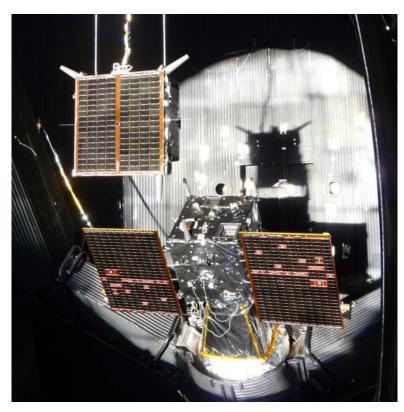




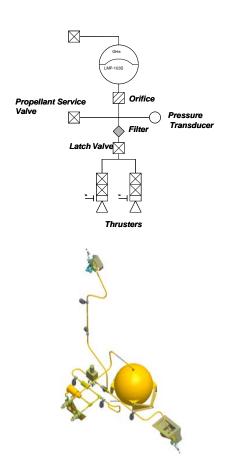


PRISMA

Autonomous Rendezvous and Formation Flying SNSB, CNES & DLR



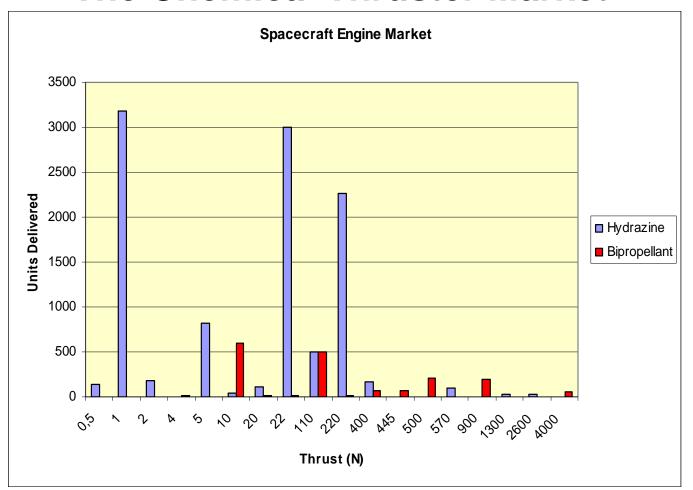
Planned Launch 2009







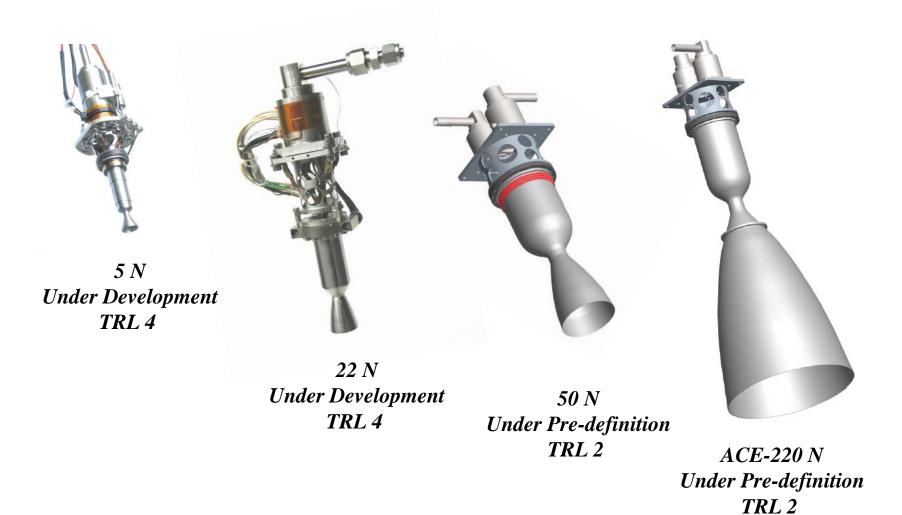
The Chemical Thruster Market







HPGP Rocket Engine Up-scaling







LMP-103S safety tests

Safety tests:

BAM Impact Sensitivity Test (mechanical impact)

BAM Friction Test (mechanical friction)

Open Fire Test (vapour ignition)

Electrostatic Discharge Test (spark ignition)

KOENEN Test (fast heating)

Small Scale Slow Cook-off (slow heating in closed container)

Detonation Test (detonation wave impact)

Micro-Calorimetric Tests (thermal stability)

Critical Diameter (diameter sustaining detonation)

Large Scale Gap Test (detonation wave sensitivity)

UN-Transport Classification Tests (transport of dangerous goods)

Material Compatibility Tests (construction materials)







PRODUCTION OF AL MIMC CASES FOR IM TESTING

Brian Gordon, Senior Program Manager Touchstone Research Laboratory

NDIA Insensitive Munitions and Energetic Materials Technology Symposium

May 11 – 14, 2009



Outline

Technology Overview

- Touchstone Research Laboratory
- Metal Prepreg Technology
- Materials
- Al MMC Lamina Properties
- Al MMC Process Background

Al MMC Cylinder Production

- MMC Design Tool Calibration and Validation
- Validation Testing
- IM and Static Firing Test Cylinders
- Conclusions and Future Work



Touchstone is an award-winning supplier of advanced materials, composites, materials testing, industrial problem solving, and outsourced R&D services to commercial and government customers.

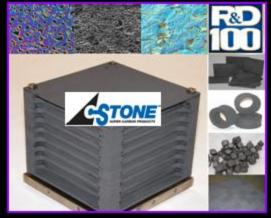




Products

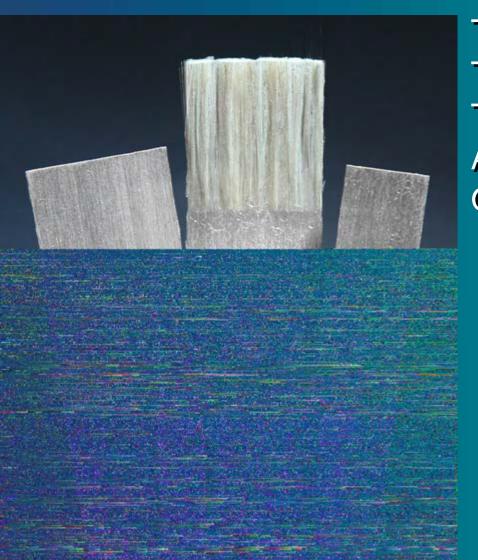








Metal Prepreg Technology



Tape Width – 0.25 to 1.50"

Tape Thickness – 0.007 to 0.020"

Tubing – 0.25" OD, 0.015" wall

Angle – 0.375" per leg, 90° angle

Other sizes and shapes possible



Fiber and Matrix Typical Properties

FIDEI alliu IVI	Toel allu Maulix Typical Plupellies				
Property	Units	Fiber	Matrix		
Chemical Composition	wt. %	>99 Al ₂ O ₃	99.99 Al		

2000

3632

10-12

4-5

 α - Al₂O₃

3.9

0.141

3100

450

380

55

0.7 - 0.8

8.0

4.4

660

1220

2.7

0.098

40-50

6-7

62

9

50-70

25

14

°C

°F

μm

in (10^{-4})

g/cm³

lb/in³

MPa

ksi

GPa

Msi

%

ppm/°C

ppm/°F

Melting Point

Filament Diameter

Crystal Phase

Density

Tensile Strength

Tensile Modulus

Elongation

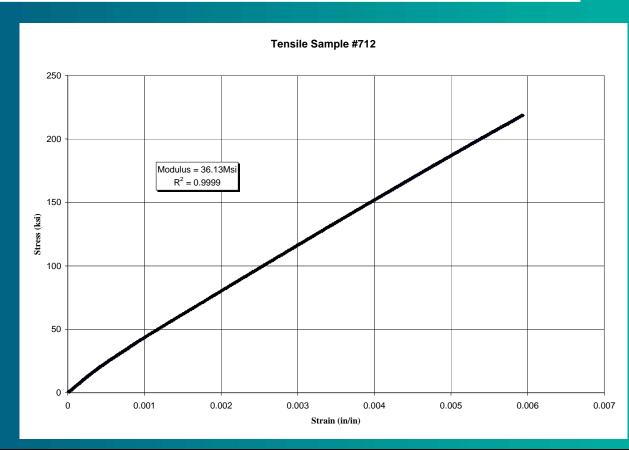
Thermal Expansion (100-1100°C)

Metal Prepreg Tape Properties

	V _f	Density (lb/in³)		Thickness (in)	F ₁ ^{tu} (ksi)		
Mean	0.50	0.119	0.377	0.0134	210	33	0.63

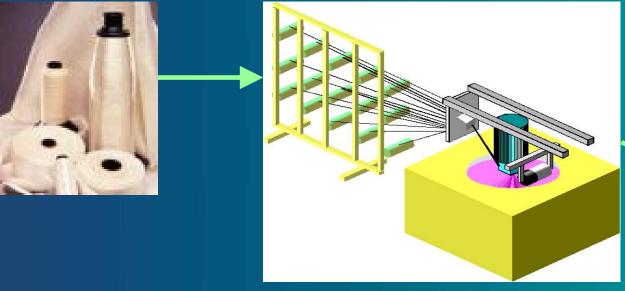
Material = Al_2O_3 fibers in pure Al Temperature = RT Environment = Air Direction = [0]

Standard Tape:
Fiber volume of 50%
Width of 0.5 inch
Thickness of 0.015 inch



Properties similar to steel but with the weight of aluminum

Metal Prepreg Filament Winding

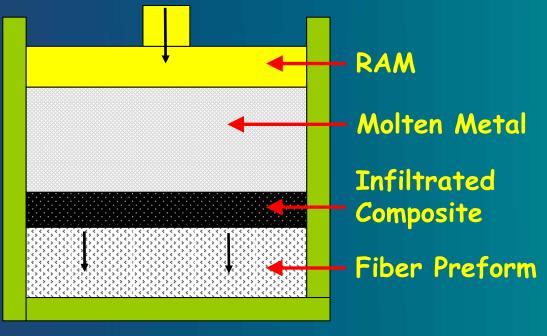




- Based on MetPreg metal prepreg technology
- Spools of fiber are put on creel
- Tension is built into each tow
- Fiber bundle is dipped into the liquid matrix (molten aluminum) to impregnate
- Impregnated fiber bundle is laid onto the mandrel

Low-cost, flexible processing for MMCs

Casting vs. Filament Winding for MIVICs



Creel

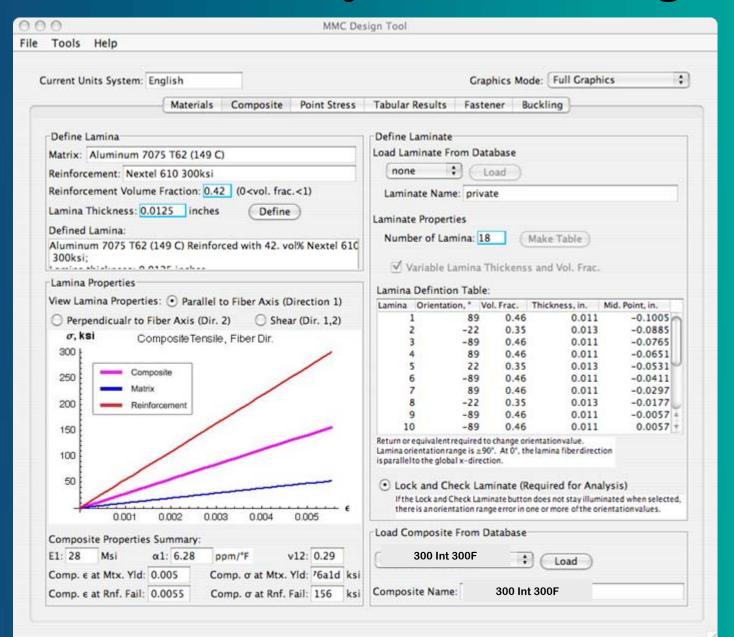
Fiber Tows

Melting
Furnace

- Pressure or squeeze casting is a multi-step process
 - Wind preform
 - Load mold
 - Melt metal
 - Infiltrate preform
- MMC filament winding is one step
 - Aluminum is kept molten in furnace
 - Fibers are infiltrated and wound in a continuous process
 - Mandrel is removed from finished part after winding

MMC Design Tool Model Calibration and Validation

Virginia Tech/Aerojet MMC Design Tool



Calibrate to Experimental Values

- Calculated mean N_y was 7030 lb/in for 4-inch diameter hoop-only cylinders $N_y = P \times r$
- Model uses a non-linear point-stress analysis to determine lamina stresses
- Stress in the fiber direction for this load is 249 ksi
- This value was put back into the model and used to predict burst pressure for a 6-ply ±45/90/90/±45 lay-up

Prediction was within 4% of experimental value

Cylindon	Assumed Fiber	Predicted Burst	Actual Burst	
Cylinder	Strength	Pressure	Pressure	

Criticalor	Assumed Fiber	Predicted Burst	Actual Burst	
Cylinder	Strength	Pressure	Pressure	

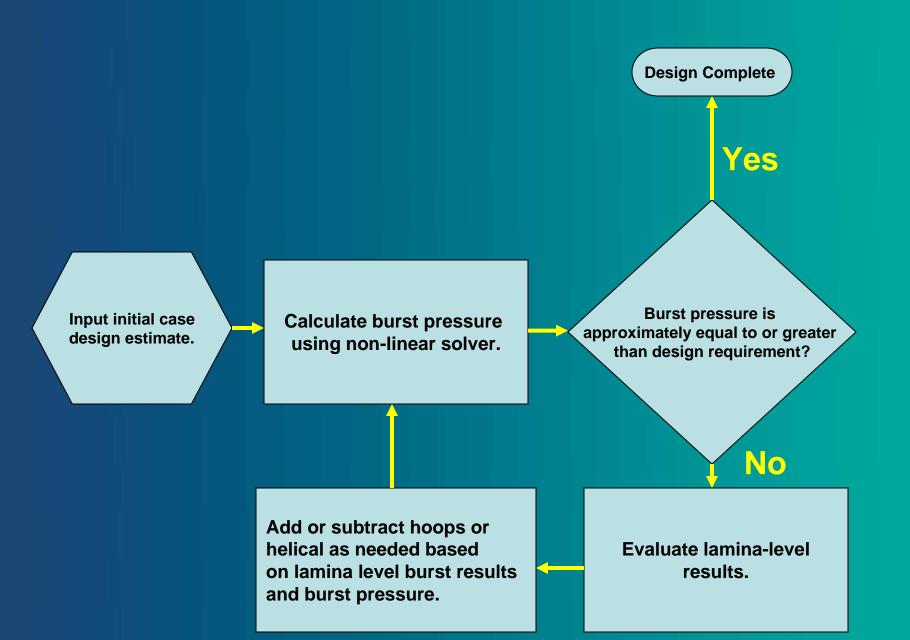
(ksi) (psi) (psi)

 $[90]_{4}$ 249 2813 2812 0

249 3250 3393 +45/90/90/+45

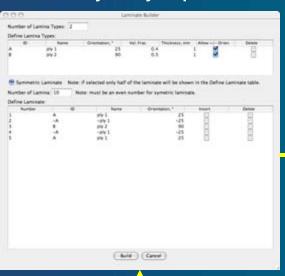
Production of Validation Test Cylinders

Case Design Using the MMC Design Tool

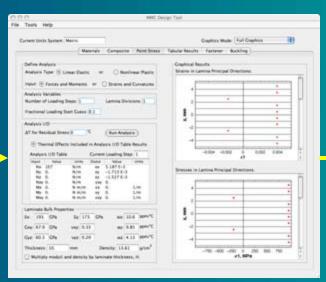


Iterative Case Design Decision Loop

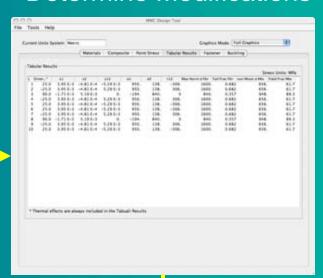
Laminate Builder - Modify Lay-up



Nonlinear Solver - Calculate Burst Pressure



Lamina-level Results - Determine Modifications

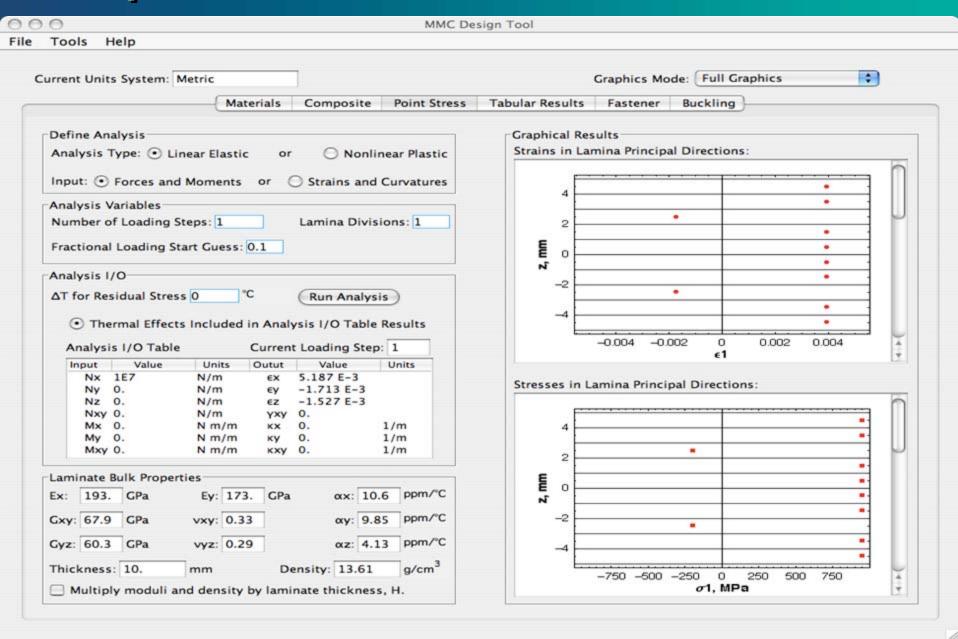


Step #1 – Laminate Builder

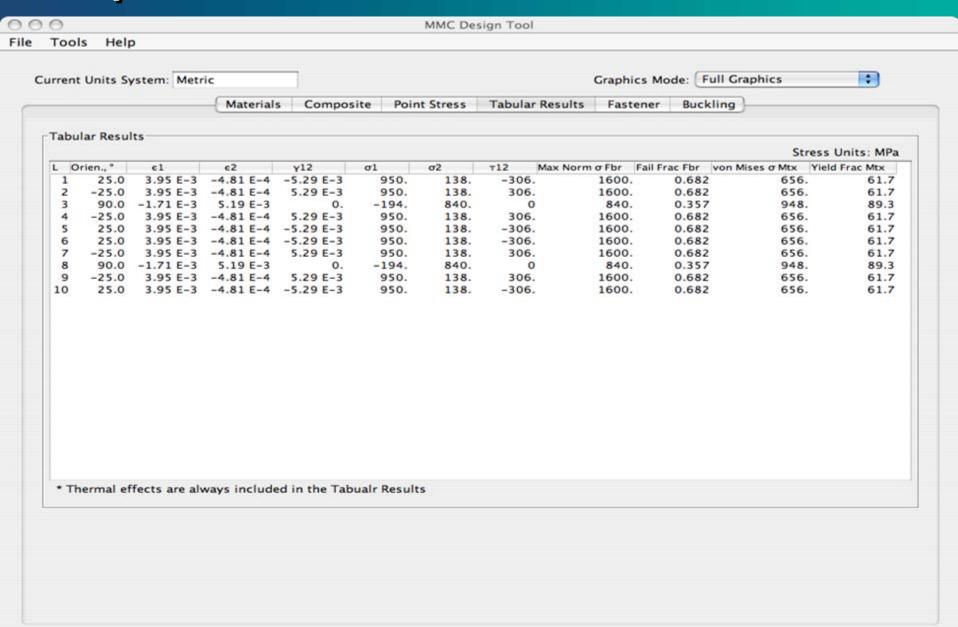
9 9		La	minate Builder			
umber of La	mina Types: 2					
efine Lamina	the property of the control of the con-	1				
ID ID	Name	Orientation, °	Vol. Frac.	Thickness, mm	Allow +/- Orien.	Delete
	ply 1	25	0.4			
	ply 2	90	0.5	1		
Symmetric	Laminate Note:	if selected only half	of the laminate	will be shown	in the Define I ami	nate table
umber of La		ote: must be an even				nate table.
efine Lamina						
Number	ID	Name	Orienta		Insert	Delete
	A	ply 1		25		
	-A	-ply 1		-25		
	В	ply 2		90		
	-A	-ply 1		-25		
	A	ply 1		25		0.00

Cancel

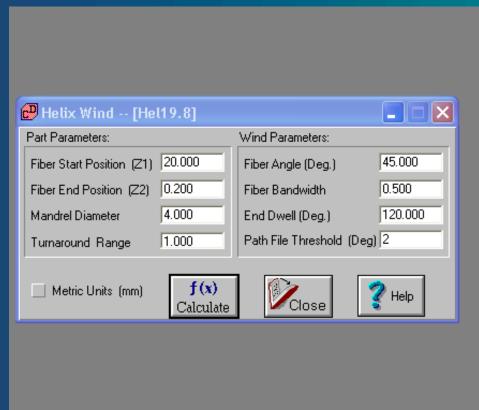
Step #2 - Calculate Burst Pressure

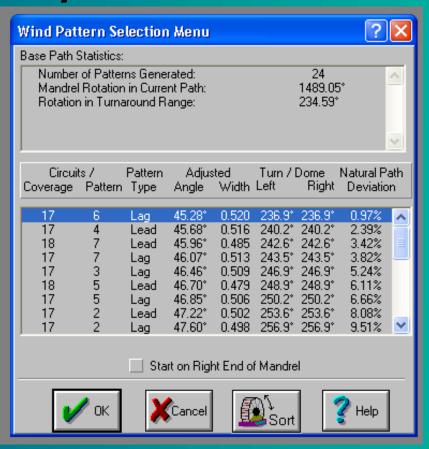


Step #3 - Review Lamina Level Results



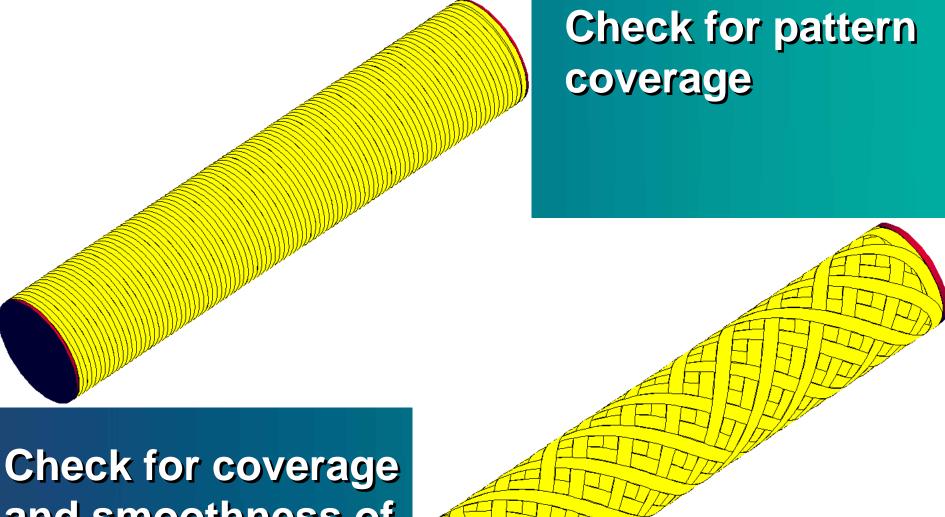
Pattern Development





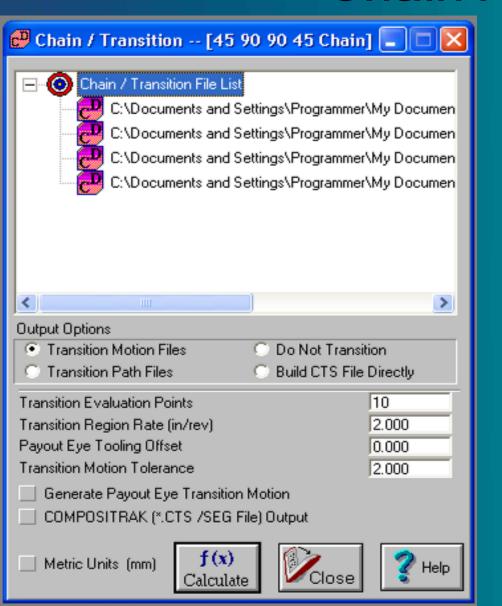
- Pattern files are created for each ply or layer
- Hoop ply patterns require the input of the mandrel diameter, pattern length, and fiber bandwidth
- Helical layer patterns require these same inputs plus the fiber angle, parameters that deal with the reversal of the fiber direction on each end, and choosing the circuits/coverage and circuits/pattern

Preview of the Winding Patterns



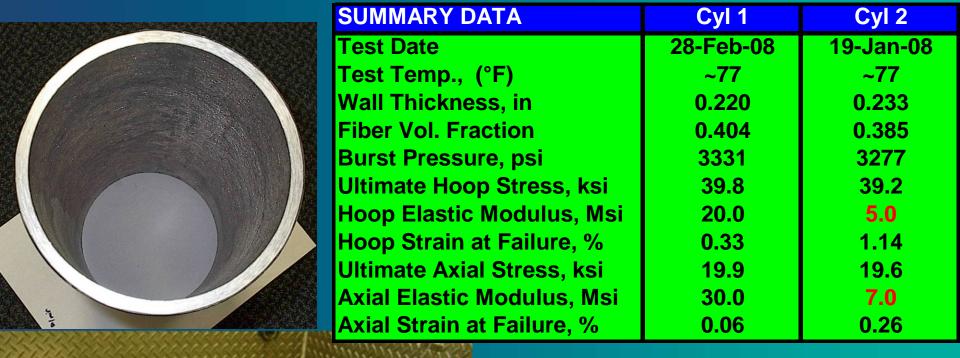
Check for coverage and smoothness of turns on ends

Combining Individual Patterns Into Chain Pattern



- Individual patterns are linked together in a chain wind to ensure smooth transitions between segments
- The pattern is "filtered" to level out any acceleration spikes in the machine motion

Validation Test Results



- Wall thickness of nearly 1/4" with a lay-up of 90/±45/ ±45/90/ ±45/ ±45/90
- Hoop fiber failure achieved
- Consistent properties with the exception of some strain data anomalies

Production of IM and Static Fire Test Cylinders

Al MMC Cylinder Production



Conclusions

- MMC filament winding process has been further demonstrated through the production of nine 6-inch OD x 15-inch long cylinders with ~0.25-inch wall thickness
- MMC Design Tool and burst test results were successfully used to design cylinders for IM and static fire testing
- Tests completed thus far indicate that Al MMC motor cases will be better than steel cases against Bl and Fl
- Al MMC cases may be better than steel in FCO as well, but the first test was not conclusive and another test is being planned
- The response to SCO should be no worse than current designs, the most difficult threat to mitigate, and there is the potential for incorporating unique closure designs specifically geared towards SCO mitigation

Future Work

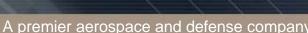
- Currently implementing a 3rd axis on the filament winding machine which should allow cylinders with thinner walls to have higher burst pressures
- Additional scale-up to make cylinders with lengths up to six feet is being planned
- A method for NDI/NDE will need to be developed
- End closure processing and attachment point designs will also need to be developed

Questions?

Visit Touchstone Research Laboratory on the Web

www.trl.com www.metpreg.com

E-mail: metpreginfo.com



Innovation ... Delivered.

High Rate Thermal Analysis of Propellant Based Cook-Off Mitigants

Dr. Andrew Sanderson

Mr. Duncan Langlois

Ms. Margaret Schmierer

April 22, 2008



Intent of Experiment



A premier aerospace and defense company

- A part of ongoing work to address improving Insensitive Munitions Cook Off Response
- This effort focused on cost-effective propellant based mitigation of Fast Cook Off
- Fast cook off phenomenology is difficult for several reasons
- Very high flux rates
- Very chaotic conditions
- High thermal gradients
- Use of propellants helps reduce risks from incompatibility, availability and manufacturability
- Intent was to examine a potential "off the shelf" solution



NTS Camden Operations



Redstone Technical Test Center

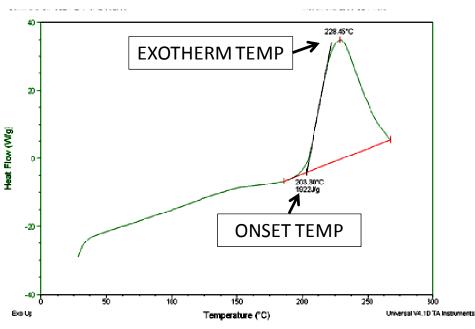


- 11 propellants from 5 types (single, double, triple, lova and high-temp)
- 46 valid runs many had to be rejected because the sample cups exploded
- The majority of propellants are NC based (this represents the state of the industry)
- Covers a wide range of ingredients, system applications, and manufacturing methods
- Samples included what were believed to have a high thermal resistance and a low thermal resistance (driven by high NG level) to serve as controls on the experiment

TYPE OF PROPELLANT	# OF PROPELLANTS	COMPOSITION
SINGLE BASE	4	NITROCELLULOSE (NC)
DOUBLE BASE	4	NC & NITRATE ESTER (NG)
TRIPLE BASE	1	NC, NG & NITRAMINE (NQ)
LOW VULNERABILITY (LOVA)	1	COMPLEX COMPOSITION
HIGH-TEMPERATURE PROPELLANT	1	NITRAMINE W/ POLYMER BINDER



- This project focused on using Differential Scanning Calorimetry to evaluate runaway thermal behavior
- Heating rates needed to be very high in order to simulate fast cook off heating rates
- Thermo-Analytical methods on energetic materials require the use of very small samples (milligram scale)
- DSC on small samples allow rapid low cost screening of multiple candidates



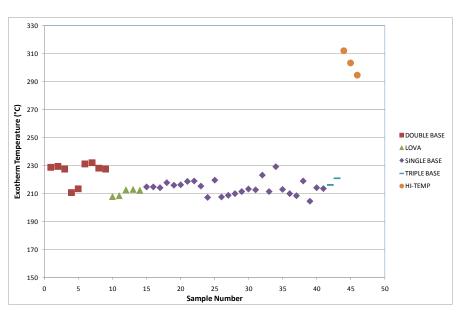


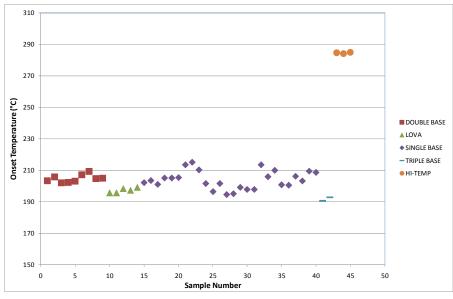


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Evaluation of Onset Temperature showed some good candidates

- Triple base had good separation from double and most single
- LOVA also had good separation from double base



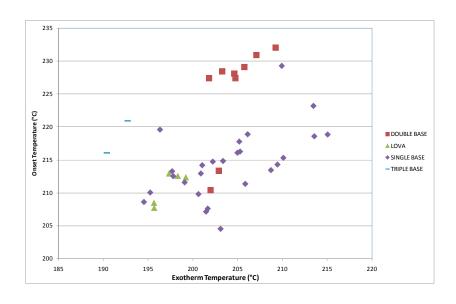


Evaluation of Exotherm Temperature highlighted conflicting data

- Triple base lost its positive separation and is a poor candidate based on exotherm
- LOVA was still low but lost its separation from double and single base propellants

Results Continued





	ONSET (°C)		EXOTHERM (°C)	
	AVERAGE	SD	AVERAGE	SD
Α	204	2.0	228	0.9
В	202	0.6	212	2.1
С	208	1.5	231	0.8
D	205	0.1	228	0.5
E	197	1.6	211	2.5
F	207	5.0	216	1.7
G	200	3.0	211	7.1
Н	202	7.1	215	7.3
I	205	3.9	212	4.6
J	192	1.6	218	3.4
К	284	0.4	303	8.7

- The relationship between Onset and Exotherm was presumed to be linear
- While true generally the data is quite messy and the different materials have different slopes
- The only clear result is that in all cases the NC based propellants are more sensitive to cook off then high temperature propellants

The primary conclusion is that according to DSC analysis, NC based propellants show little difference in cook off behavior

The low thermal resistance propellant turned out to have similar behavior to the other NC based propellants

For materials that are very thermally stable NC based propellants could be effective cook off mitigants

More work has to be done, the "off the shelf" method didn't work out, but some simple modifications may pay high dividends



- Examine the effect of doping NC based propellants with energetics that have a low thermal sensitivity
- These energetics do not necessarily need to be novel or expensive materials.
 There are several promising candidates that are energetics that have been previously used by the defense community but never made it to common use
- Upgrading the evaluation method to one that uses larger samples would be a positive change – Several improved methods exist
 - Open burning (DOT method with improved instrumentation)
 - Simulated Bulk Autoignition Testing (Probably the ideal candidate but requires special equipment)
 - Small Scale Cook Off tests (several are available, each lab has a favorite, no one has really caught on yet)



IM Technology and Munitions Insensitive Munitions Technology Tool IMT2

IMEMTS

Tucson, AZ

May 2009

Ken Tomasello

Insensitive Munitions Office

Naval Ordnance Safety & Security Activity

301-744-6078

Ken.tomasello@navy.mil



Background

Observation/Problem:

- Large number of ongoing S&T/R&D IM programs across the DoD community JIMTP, IMAD, IMTTP, MDA SBIR/STTR, Army/Navy/AF Inhouse, Munitions Risk Reductions
- No single source for easy access and dissemination of ongoing IM technology development efforts and munitions shortfalls to the S&T/R&D community, Munitions Program Managers

Approach:

 Develop a one-stop shopping relational interactive website that will allow instant access to technology developments and munitions needs.

Solution:

- "INSENSITIVE MUNITIONS TECHNOLOGY TOOL" (IMT2)
 - ✓ Website DSTKOL
 - S&T/R&D Project Quad Charts
 - ✓ Available IM Technology

- ✓ Relational and User Friendly
- Munitions IM Quad Charts
- ✓ JIMTP MATGS Focus Areas



Objectives – Improve value and impact of IM data

- Develop a <u>user friendly relational management tool</u> for S&T and advanced development programs along with available technologies correlated with Joint service primary goals.
- Identify ongoing <u>S&T and advanced development</u> <u>programs</u> with <u>munitions</u> IM technology <u>shortfalls</u>.
- Eventually <u>establish an IM technology roadmap</u>
 <u>throughout DoD</u> to facilitate program planning, sponsor support and execution.

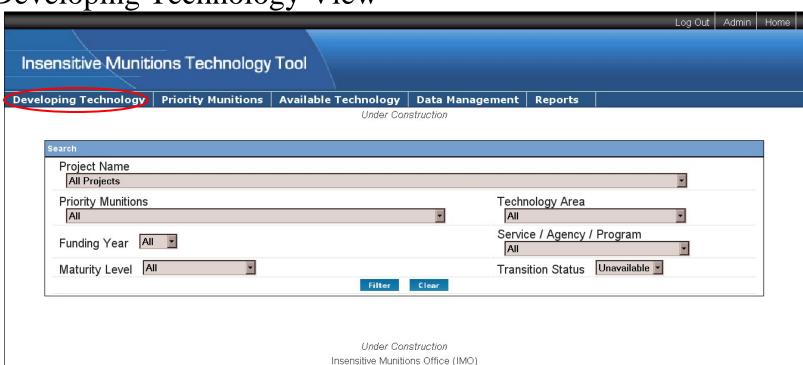


IMT2 Landing Page (after login via username/password)





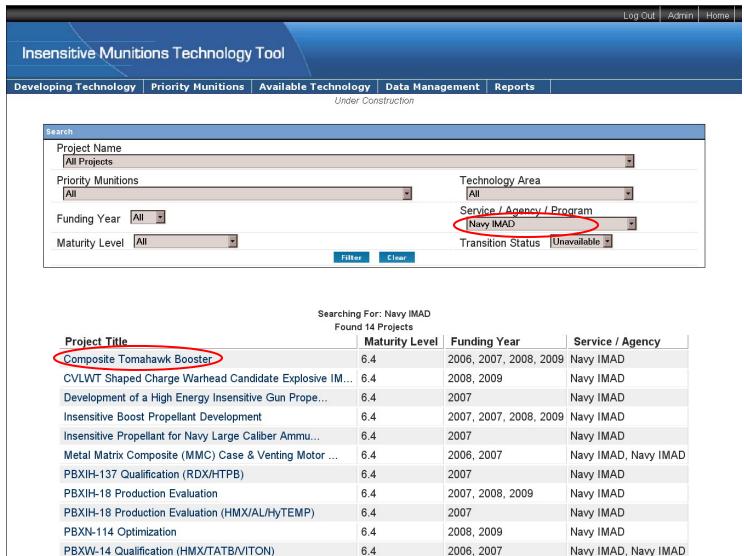
Developing Technology View



Insensitive Munitions Office (IMO)

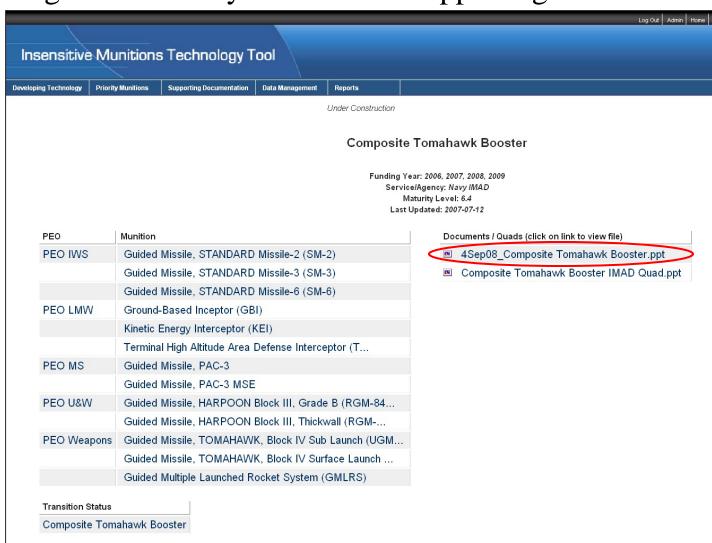


Developing Technology, Navy IMAD Search



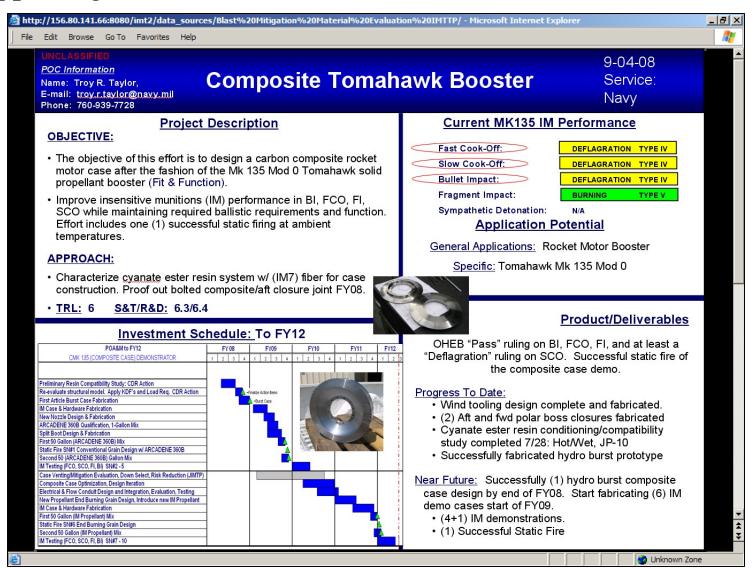


Program Summary and Link to Supporting Data



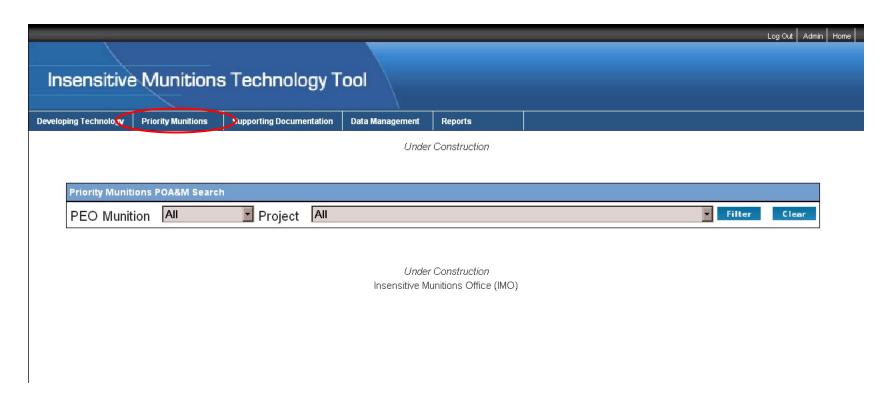


Supporting Data



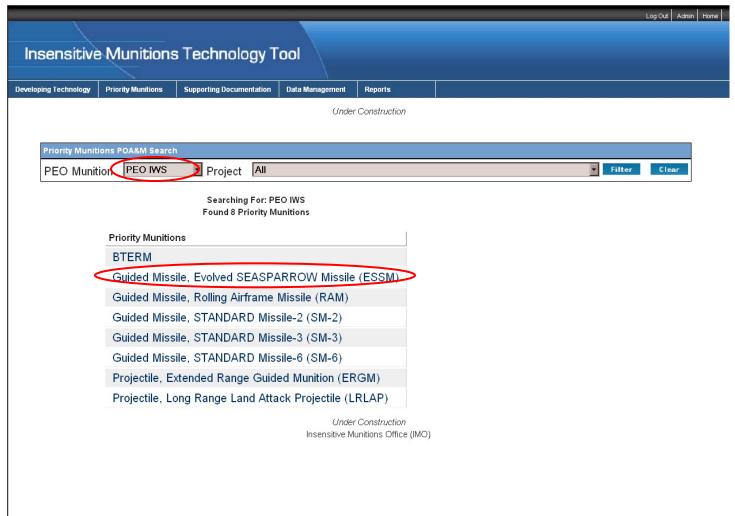


Priority Munitions View



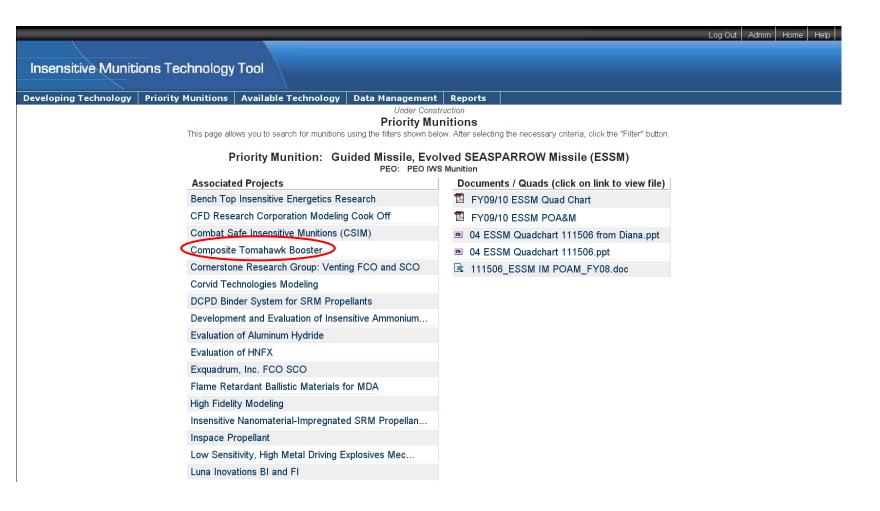


Priority Munitions, PEO IWS Search





Priority Munition Summary and Link to Supporting Data





Community

Today

- S&T/R&D IM Community
 - Investigators
 - PMs/TDs
- Joint Staff
- OUSD Office of Munitions
- Services IM Offices
- PEO IM Coordinators
- Munitions Programs

Future

- Defense Organizations
 - JANNAF
 - NDIA
 - AIAA
- Prime Contractors
- Sub Contractors
- Acquisition Executives



Benefits Summary

- Web Enabled
 - Browser based intuitive navigation
 - Ease of access to data, reports and analysis
- Data Management
 - Role based user access
 - Data reliability, change management and audit trails
 - Data entry by 'data owners' pushes the responsibility of data 'up to dated-ness' to data owners
- User Community
 - Scalable to meet the needs of a growing community



Next Steps

- Pilot Program
 - April 01-30
- Resolution of Feedback/Findings from Pilot Users
 - May 01-31
- Production Target
 - June 15



Thank you



Update on HTPE Propellant Service Life

Insensitive Munitions and Energetic Materials Technology Symposium Tucson, Arizona

May 2009

Ted Comfort and Steve Grow Allegany Ballistics Laboratory Rocket Center, West Virginia



Background for HTPE Propellants



- Based on hydroxyl-terminated polyether (HTPE) polymer manufactured by ATK
 - Uses ammonium perchlorate and ammonium nitrate oxidizers and BuNENA plasticizer
- Under development and production by ATK for over 20 years
- ATK developed tactical aluminized and reduced smoke HTPE propellants for improved insensitive munitions (IM) response
 - Rocket motors manufactured from HTPE propellants have demonstrated improvements in IM performance
 - HTPE passed 6-inch diameter zero card gap test
 - non-detonable for motors with webs up through six inches
- Over 1000 HTPE propellant mixes of various sizes and over 2500 motors manufactured



An advanced weapon and space systems company

- Over 90 separate HTPE propellant mixes have been aged at various temperatures for stabilizer content and/or mechanical property measurements
 - Gas generation and burning rates have also been measured on some propellants
- Many direct comparison measurements have been made to deployed tactical minimum smoke propellants which demonstrate that HTPE propellants have equal or longer service life
 - Over 40 propellant mixes aged at 165°F (74°C) the standard database temperature for minimum smoke propellant aging
- Long-term aging study being conducted on HTPE propellant
 - 15-year aging data presented

HTPE Compared to Minimum Smoke Propellants



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Aging mechanism is the same

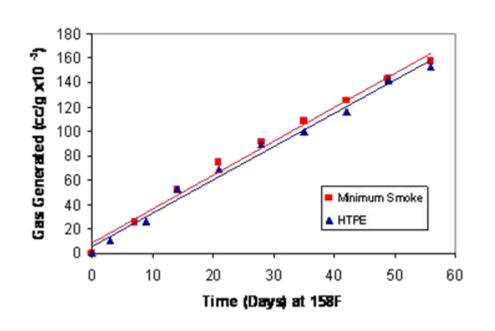
Both have polyurethane binders plasticized with nitrate esters

BuNENA compared to NG/BTTN

Both stabilized with N-methyl-pnitroaniline (MNA) and 2nitrodiphenylamine (NDPA)

Over time the nitrate esters degrade and the stabilizers remove the generated nitrogen oxides to prevent autocatalysis and attack on urethane crosslinks

Effective gas generation and service life is the same for both for HTPE and minimum smoke propellants



Stabilizer Depletion and Service Life



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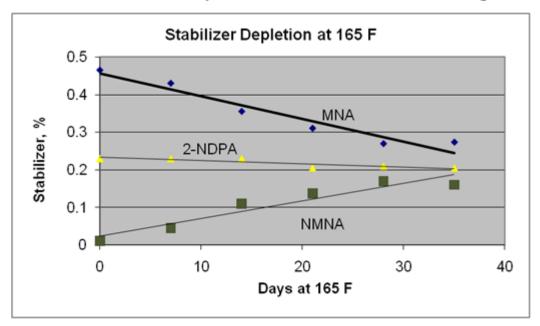
 Studies have shown that when the MNA stabilizer concentration goes below 0.10% service life (at high temperature) will end due to rapid gas generation and propellant softening for both HTPE and minimum smoke propellants

 MNA depletion can be easily measured during propellant aging to measure service life

 Based on MNA depletion rate data at various temperatures the activation energy can be calculated and the service life at other temperatures or temperature cycles can be calculated

An advanced weapon and space systems company

- In a typical test the propellants are withdrawn from aging periodically and a sample is analyzed for MNA, NDPA and nitroso-MNA (NMNA) the MNA depletion product
 - Mechanical properties are often measured at the beginning and end of the aging period
- MNA depletes in a linear fashion and is converted to NMNA
 - NDPA concentration is fairly constant until the MNA goes below 0.10%

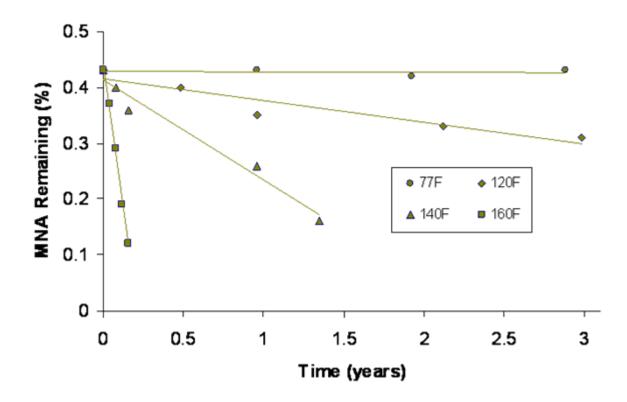


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Stabilizer Depletion for Aluminized HTPE



- MNA depletion measured at four temperatures
 - In this study there was no measurable stabilizer depletion in three years at 77°F (25°C)

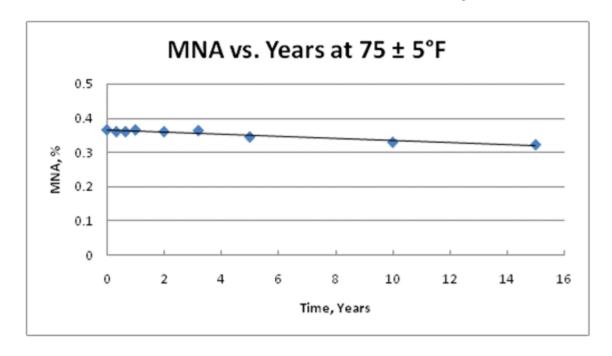


Stabilizer Depletion for Long Term Aging



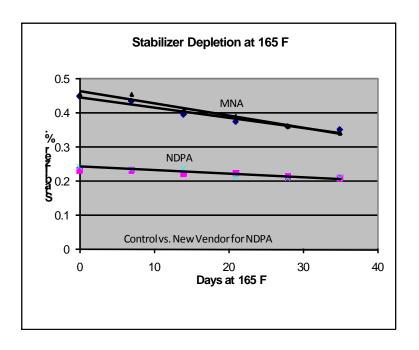
An advanced weapon and space systems company

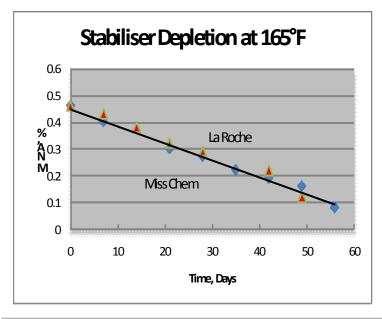
- In a test of stabilizer depletion for HTPE propellant there was a steady slow decrease in MNA content over fifteen year time period
 - Data was averaged from two 50-gallon propellant mixes made in 1993
 - Initial MNA content was increased subsequent to these mixes
- MNA content is calculated to reach 0.10% in 125 years at 75±5°F (25±3°C)

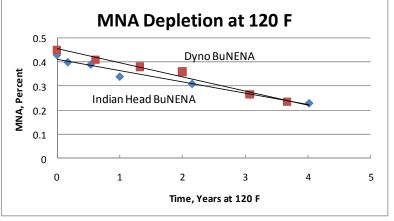




 As in many motor production programs new suppliers for ingredients are required from time to time

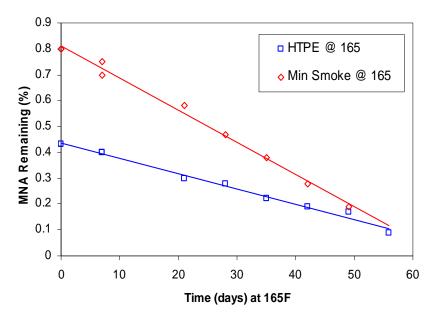


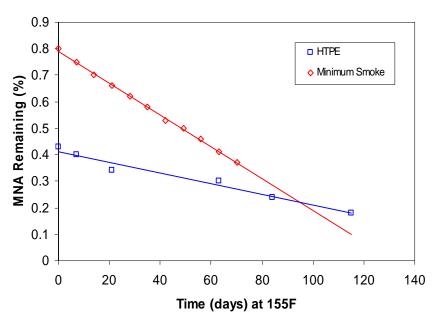






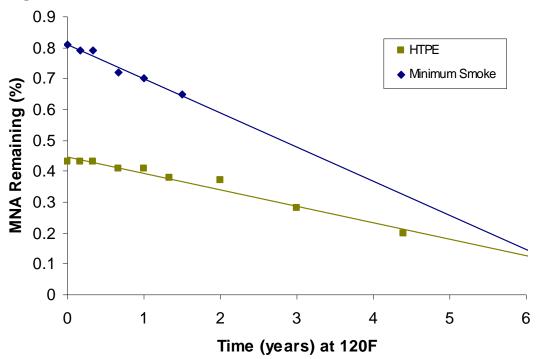
- HTPE propellants are formulated with about half the initial stabilizer content of minimum smoke propellants
- MNA stabilizer depletes at about half the rate in HTPE propellant than it does in minimum smoke TOW and Hellfire propellants
- Time to reach 0.1% MNA is about the same for HTPE propellant, therefore service lives based on stabilizer depletion will be the same
 - Over 40 HTPE mixes tested at 165°F (74°C)



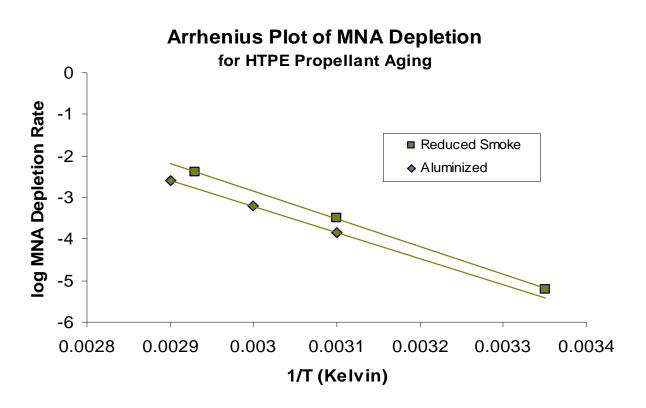




- MNA depletion time to 0.1% is projected to be about six years at 120°F for both HTPE and minimum smoke propellants
- Expect to have the same service life based on stabilizer depletion
- Minimum smoke propellants in TOW and Hellfire motors have demonstrated acceptable service life in a variety of tactical storage conditions



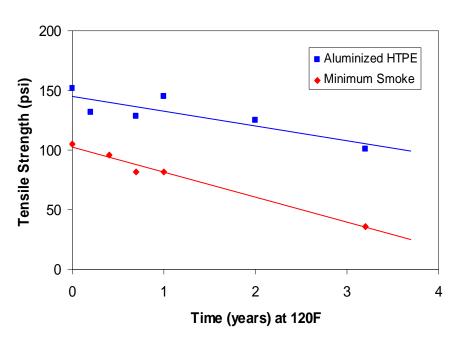
- Same activation energy range as for minimum smoke propellants
 - Ea = 26 to 29 kcal/mole
- Can calculate MNA depletion time at any temperature or temperature cycle

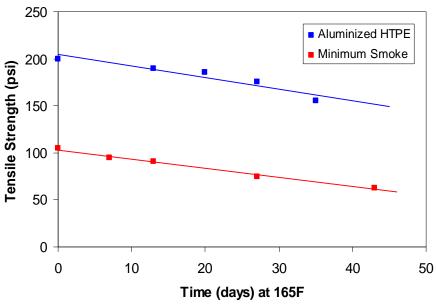


Tensile Strength Aging of HTPE Propellants



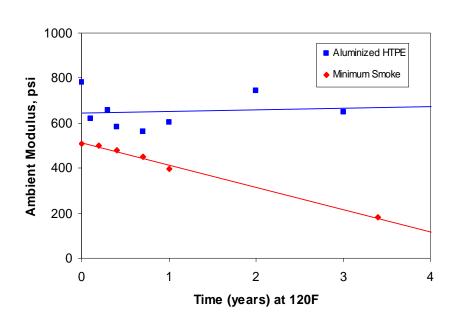
- Mechanical properties of HTPE propellants are more stable than currently deployed minimum smoke propellants
 - During aging tensile strength and modulus decrease and strain increases
 - Mechanical property aging has been measured at 77, 120, 155 and 165°F
- Tensile strength comparison for propellants aged at 120 and 165°F

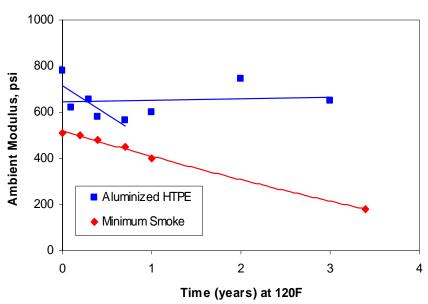






- Modulus of HTPE propellants are more stable than currently deployed minimum smoke propellants
 - Mechanical property aging has been measured at 77, 120, 155 and 165°F
- The second chart below shows that extrapolating initial data can sometimes lead to the wrong service life prediction

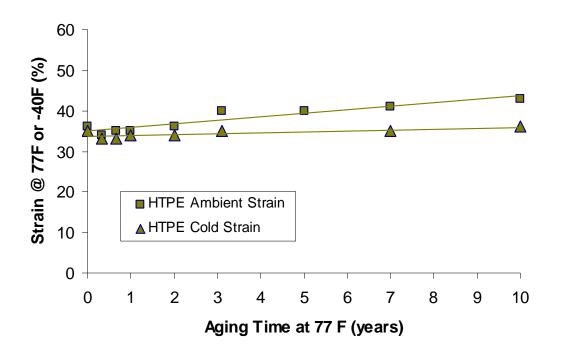




Strain Aging of HTPE Propellants



- Strain capability of HTPE propellants slowly increases with aging time
 - Similar behavior to minimum smoke propellants
- Ambient and cold (-40°) allowable strains increase slowly during ten-year ambient storage for HTPE propellant



Fifteen-Year Propellant Aging



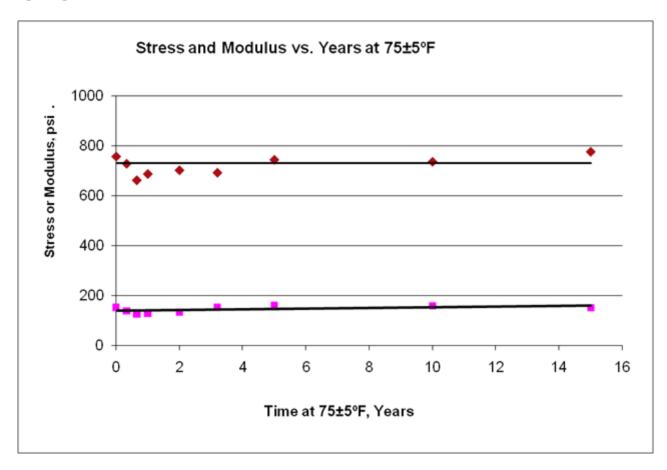
- Propellants in this study are HTPE formulations manufactured in two 50gal mixes in 1993
- Storage temperature is $75 \pm 5^{\circ}F$ ($25 \pm 3^{\circ}C$)
- The only changes in properties after fifteen years aging were a small decrease in MNA content
- Stabilizer depletion projects to very long service life

Property	Initial	Five Years	Ten Years	Fifteen Yrs
77ºF Stress, psi	152	161	158	150
Strain, %	36	40	42	34
Modulus, psi	757	744	737	776
-40ºF 0.02 ipm Strain, %	35	35	36	-
MNA, %	0.365	0.345	0.33	0.323
2-NDPA, %	0.24	-	0.24	0.255

Fifteen-Year Propellant Aging



 Mechanical properties of HTPE propellants are very stable under longterm aging

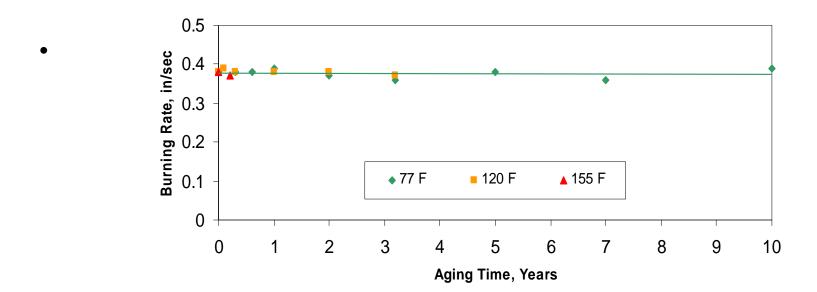




•Extensive aging tests have also been performed using case bond samples and dual propellant specimens that demonstrate the long term stability of

 The activation energy for tensile strength and modulus changes is about 28 kcal/mole, the same value as for stabilizer depletion

Burning rate is also stable during long term aging



HTPE propellants

Summary



- Aging data was obtained on over 90 different HTPE propellant mixes demonstrating long term service life
 - Based on gas generation, stabilizer depletion, mechanical property and burning rate measurements over aging times as long as fifteen years
- HTPE propellants are projected to meet tactical motor service life requirements as extreme as those actually experienced by TOW and Hellfire motors now deployed around the world

- Word of caution: To obtain long service life ingredients must be selected that are compatible with BuNENA nitrate ester
 - For example, many suppliers of commercial ammonium nitrate use anticaking agents or phase stabilizers that accelerate the decomposition of BuNENA



IM Response for Army Engineering Charges filled with FPX V40



2009 IM/EM
Technical Symposium
May 11th-14th 2009
Tucson, Arizona

Hannu Hytti, M.Sc. (Eng.)
Forcit Defence



IM Response for Army Engineering Charges filled with FPX V40

- Background
- Qualification of FPX V40 according to STANAG 4170
- IM testing
 - BI, SH, FH, SR, FI (mod)
- CBAM calculation for Forcit DFC 2010 System and comparison with conventional non-IM-system



Background

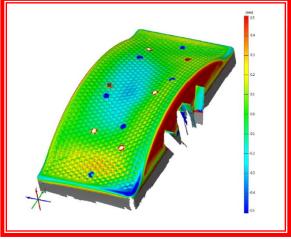
- Replacement of infantry mines and old army engineering equipment in FDF
- Forcit In-house development of IM products
- A new FPX development to replace e.g. hexotol in army engineering charges
- FPX V40 suitable for e.g. Directed Fragmentation Charges and Mine Clearance Charges



Background

- Forcit DFC 2010 is based on the FPX V40 main charge and FPX R1 booster charge
- For the best performance of the product a suitable combination of bubble- and shock energy was developed
- In-house development included field testing and 3 D-modelling of the charge







General information FPX V40

FPX V40	
Type:	General purpose, army engineering charges
Components:	RS-RDX, AP, AI, binder
Density:	1,72
Velocity of detonation	6600 m/s
UN test series 7	Pass (except EIDS Gap)
STANAG qualified	Yes
IM-tested	Yes



Qualification of FPX V40 according to STANAG 4170 and the effect of ageing (1/2)

TEST	FRESH	3 MONTHS	6 MONTHS	Note
Impact sensitivity, BAM (cm) STANAG 4489	39	41	58	
Friction sensitivity (N) STANAG 4487	252	168	160	
LSGT (NOL) (mm/kbar)	31 / 41	31 / 41	31 / 41	
Deflagration point (° C) STANAG 4491 B1	211	213	213	
DSC (° C) STANAG 4515	227,3	226,3	223,5	
Thermal expansion coefficient α (1/° C) STANAG 4525	9,4E-05	10,3E-05	10,7E-05	
Slow Cook Off (° C) STANAG 4491 Annex C-3	168/explosion	172/expl.	172/expl.	Acc. UN EIDS SCO pass
Fast Cook Off (° C) STANAG 4491 FCO-tube	Deflagration			
Koenen test (mm)	No det./2 mm			

 Sensitivity properties and thermal stability as well as mechanical properties not significantly changed during ageing



Qualification of FPX V40 according to STANAG 4170 and the effect of ageing (2/2)

- Slow Cook Off –reaction
 - According to STANAG 4491 Annex C : explosion
 - According to UN EIDS Slow Cook Off: pass







IM testing: Bullet Impact STANAG 4241 ed 2 (1/2)





IM testing: Bullet Impact STANAG 4241 ed 2 (2/2)

- Impact on the front side of the charge and direct on the booster
- Reaction level: Type V, no reaction







IM testing: Slow Heating STANAG 4382 ed 2



 Reaction level : Type V, burning



IM testing: Fast Heating STANAG 4240 ed 2



 Reaction level : Type V, burning



IM testing: Sympathetic Reaction STANAG 4396 ed 2



Reaction level :
 Type V-IV, burning deflagration



Sensitivity to Fragment Impact

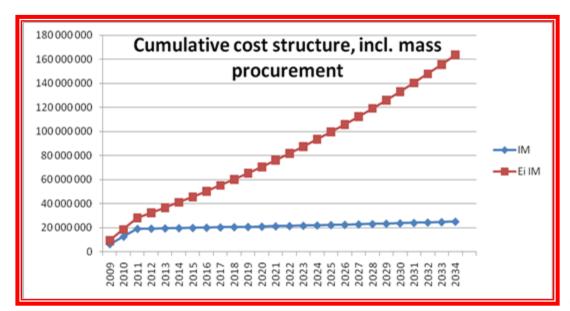


- Another DFC was fired towards the acceptor charge with differer distances between the charges (80 cm – 0 cm)
- Reaction level : Type V, burning



CBAM calculation

- Cost Benefit Analysis Model based on the IM testing of the Forcit DFC 2010
- Calculated for 25 years lifecycle and compared to a conventional DFC
- The cost for Forcit DFC 2010 was 15 % of the total lifecycle cost of the conventional DFC.





Summary

- The replacement of infantry mines and obsolete army engineering charges have given cause to a development of new army engineering charges with IM properties
- FPX V40 and FPX R1 are suitable explosive fills e.g. army engineering charges and give excellent performance and IM properties.
- There is a huge potential of storaging cost savings with Forcit DFC 2010 if the potential would be fully utilized (UN Test series 7 renewal)



Acknowledgements

Finnish Defence Forces Test Firing Centre

Finnish Defence Forces Technical Research Center

Forcit Defence team



Bofors Test Center

Cost-efficient test methods in the insensitive munitions (IM) program

R Lindström, K Sånebo

A presentation to: The 2009 Insensitive Munitions & Energetic Materials Technology Symposium

14.5.2009



Contents

- 1 Introduction
- 2 Liquid propane gas test Equipment
- 3 High velocity fragment impact gun
- 4 Conclusions

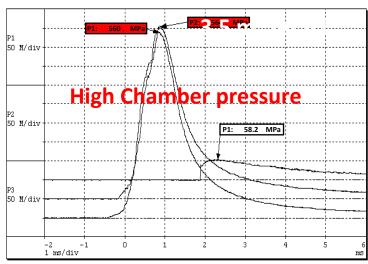


Introduction

Increased demand (from industry and regulatory bodies alike) for more cost-efficient and more environment-friendly testing.

- Fast cook-off (FCO) test.
- High fuel costs
 - High time rate
 - Environmental impact
- Fragment impact (FI) test
- Equipment wear





Fast cook-off with liquid propane gas (LPG)

- •Fuel cost reductions •Shorter run times 30 40% lower costs in single tests.







- •Good flexibility (up to 4 tests a day).
- •Improved evaluation of the tested object's reaction sequence (high speed video).
- Less testing to evaluate design solutions
- Environmental friendly









- •Ignition of the system is remote and uses electric sparks.
- Matched to the set temperature requirements detailed in STANAG 4240.
- •The equipment is best suited for testing small, complete weapon systems or subsystems from large configurations.



Verifying the LPG system

During the development phase the equipment was verified by comparative testing using three IM qualified products:

1. 40 mm, L70 LK cartridge case assembly.





- 2. Launch Rocket on the New Light Antitank Weapon (NLAW) system.
- 3. Flight motor NLAW system.





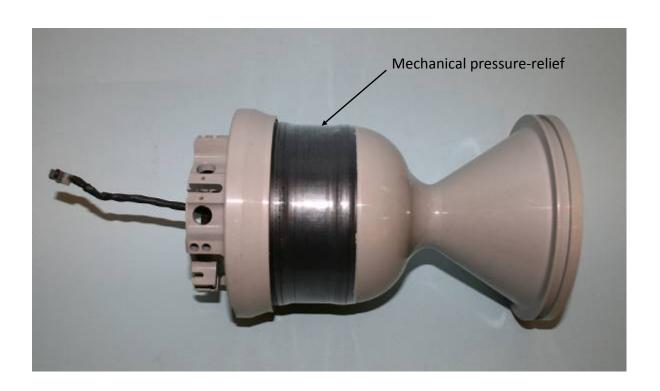






NLAW launch rocket test

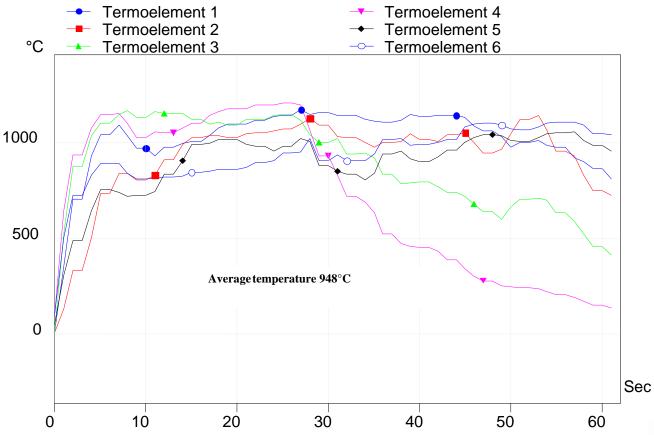
- Mechanical pressure-relief IM solution.
- •The design generates a reaction that is classified as a Type IV, deflagration under NATO AOP-39 using Jet A1.





Temperature registration

- •From the start of the fire sequence to the temperature at the object reaching 550°C satisfied the 30-second requirement.
- •Temperature was calibrated to the desired value (> 800°C).



Results after performing test

- Pieces were recovered > 15m from the point of reaction.
- •The recorded sound pressure was at the same level within the limit value of < 5kPa at 5m
- •The radiation intensity was not registrable 15 m from the object.
- After the reaction, no damage to the witness plates was observable.



LPG Test of launch motor for the NLAW system reaction no.1



LPG Test of launch motor for the NLAW system reaction no.2

- •The object split into < 3 pieces.
- •Recovered pieces bore witness to the balanced functioning of the mechanical pressure-relief IM solution.



Remaining parts of the Launch motor after FCO test with Jet fuel.



Remaining parts of Launch motor after FCO test with LPG.

High velocity Fragment Impact (HFI) test equipment

- Demand for fragment impact (FI) testing is growing ever more rapidly.
- •Higher fragment speed (2,530±90 m/s) according to STANAG 4496 is requested.





- Increased lifetime
- Standard components used

Cost reduction



Gun system

- •Two smooth-bored, 40 mm, L/70 barrels.
- vacuum system in the barrel to increase velocity.

Ammunition

- •Ammunition is based on standard components for the 40 mm, L/70 system.
- •The fragment is mounted in a sabot divided in to two pieces made of Plexiglas.
- •The fragment used is a 14.3mm diameter steel rod with a 160° conical nose according to STANAG 4496.



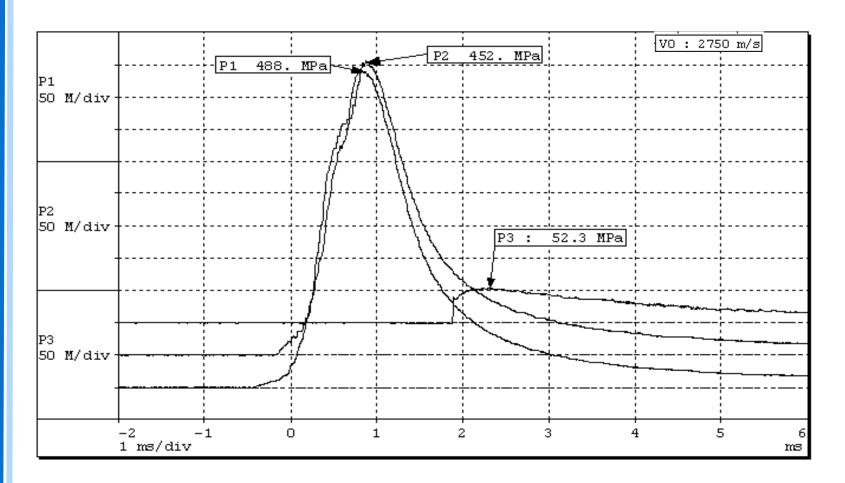
Plexiglas sabot with standard fragment



Complete FI ammunition assembly



- •God muzzle velocities > 2700m/s.
- •The fragment's stability and muzzle velocity give a practical firing distance of > 15 m.
- •Minimal wear of both the chamber position and the barrel



Conclusions

Fast cook-off with liquid propane gas (LPG)

- Fuel cost reductions
- Shorter run times
- Good flexibility (up to 4 tests a day).
- Les testing to evaluate design selusions
- •Improved evaluation of the tested object's reaction sequence (high speed video).
- Environmental friendly

High velocity Fragment Impact (HFI) test equipment

•Increased lifetime
•Standard components used Cost reduction





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Questions

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Roxel IM technology, analysis of trial results, future IM programmes in France and UK

IMEMTS – 14th May 2009 Andrew Strickland, Jean-Claude Nugeyre, Raymond Coleno, Didier Zanelli





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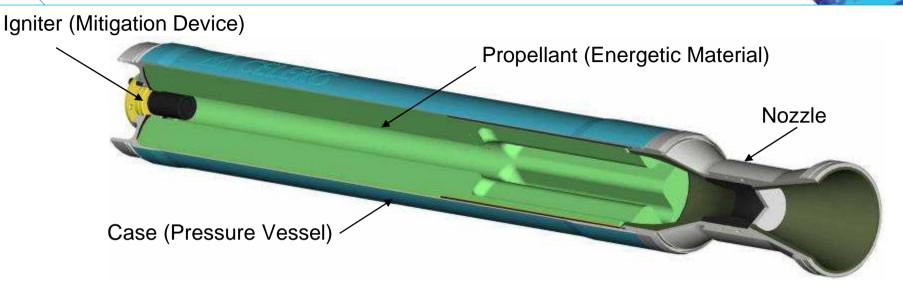
Summary

- 1. Introduction
- 2. Roxel's main IM trial results
- 3. Analysis of test results and key technology
 - Propellants, Cases, Mitigation devices and Modelling
- 4. Challenges with RM IM response assessment
 - Influence of test conditions
 - Interpretation of test results
- 5. IM technology gap and new research areas
 - French MOD ARP APTE programme
 - UK programmes
- 6. IM low cost design methodology
- 7. Conclusion





Introduction: Rocket Motor Overview



A Rocket Motor (RM) must deliver thrust, by expansion of hot gas generated by an Energetic Material (propellant) burning under pressure in a case (pressure vessel), through a nozzle, at any moment of its life time.

Insensitive Munition (IM) RM must minimise the probability of inadvertent initiation and the severity of subsequent collateral damage to weapon platform logistic systems and personnel when subject to an unplanned stimuli.

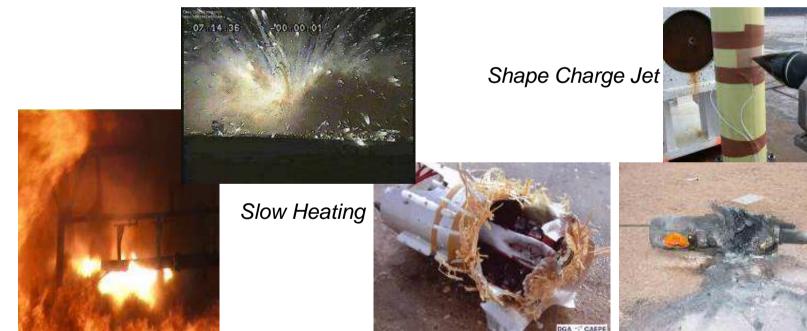
This requires designers to meet this complex challenge to achieve a fully IM compliant RM able to deliver the maximum desired energy.





Introduction: Roxel IM Approach

- IM response of a Rocket Motor (RM) is a critical requirement
- For over 15 yrs Roxel has developed an IM technology design approach based on:
 - Understanding of the behaviour of energetic materials and RM reactions under stimuli
 - Modelling and calculations
 - Participation of Roxel experts in international IM groups
 - Database setup of more than 200 IM trials on demonstrators and RM's





Fragment Impact





Acronyms

List of key acronyms within presentation

ALU	Aluminium	IM	Insensitive Munition
AP	Ammonium Perchlorate	KOA	Kevlar Overwrap Aluminium
APTE	Amelioration Propulsion Tactique	LMA	Low temperature Melting Alloy
ARP	Advanced Research Programme	LTI	Low Temperature Igniter
ВІ	Bullet Impact	MD	Mitigation Device
CDB	Cast Double Base	NG	Nitro Glycerine
CF	Carbon Fibre	PID	Pre Ignition Device
CFRP	Carbon Fibre Reinforced Plastic	PV	Pressure Vessel
EDB	Extruded Double Base	REF	Reference
EM	Energetic Material	RM	Rocket Motor
EMCDB	Elastomeric CDB	RRPR	Reduced Range Practice Rocket
FH	Fast Heating	SCJ	Shaped Charge Jet
FI	Fragment Impact	SDT	Shock to Detonation Transition
GAP	Glycidil Polyazoture	SH	Slow Heating
HBR	High Burning Rate	SMA	Shape Memory Alloy
HFI	Heavy Fragment Impact	SR	Sympathetic Reaction
HTPB	Hydroxy Terminated Polybutadiene	SSL	Steel Strip Laminate
HTPE	Hydroxy Terminated Polyether	XDT	Delayed Detonation Transition
HVM	Hyper Velocity Missile	XLDB	Cross Linked Double Base
HVSG	High Velocity Shot Gun		

• References used in the subsequent table are used throughout the presentation to refer to corresponding trial results: [27] refers to trial result "Ref 27" in table Page 6





Selection of Roxel IM Test Results

Ref.	Specimen Status	IM Characteristic of rocket motor (tested)										
Kei.	Specimen Status	Propellant Case Mitigation Technology						FI	HFI	SR	SCJ	
	NATO STANAG 4439		V	V	V	V		III	III			
	FRANCE INSTRUCTION	DGA 260 IPE MUR	AT ***		V	V	V	V	IV	IV	Ш	
2	RM In Service	EDB	Alu.	-	V	V	N/R			1		
3	RM. Demonstrator	EDB	Alu.	-	V	V	V	N/R		<iii< td=""><td></td></iii<>		
5	RM. Demonstrator	EDB	SSL	V	V	V						
9	RM. Demonstrator	EDB S1	Alu.	-	V	IV	V			1		
10	RM. Demonstrator	EDB S2	Alu.	-	V	IV	V			<iii< td=""><td></td></iii<>		
11	RM In Service	CDB	KOA	-	IV	III	IV			III	- 1	
12	RM In Service	EDB	KOA	-	IV	IV	IV			V	IV	
13	RM In Service	EMCDB	SSL	-	V		V					
14	RM In Service	Composite	Alu.	-	V		V					
15	RM In Service	CDB	KOA	-	V		V					
16	RM. Demonstrator	EDB	KOA	-	V		N/R					
17	RM. Demonstrator	XLDB 2	CRFP	-	V		N/R					
18	RM under Qualification	CDB	KOA	-	V		V					
19	RM under Qualification	CMDB	KOA	-	V		V					
20	Tech. Demonstrator	Composite	KOA	LTI (Low Temperature Igniter)	V	IV						
21	RM In Service	EDB	Steel	-	IV	IV	V	- 1		II	1	
22	RM. Demonstrator	GAP Comp.	KOA	-	V		N/R					
23	RM In Service	Composite	SSL	LTI	V	IV	V					
24	RM In Service	Composite	Steel	Intumescent paint	V							
25	RM. Demonstrator	Composite	Steel	Membrane	V							
26	Tech. Demonstrator	CompositeHTPE	SSL	-	V	III	III					
27	RM. Demonstrator	CompositeHTPE	SSL	LTI	IV	- 1	IV		III		IV	
28	RM In Service	Composite 1	Steel	-	III		V					
29	RM. Demonstrator	Composite 1	Steel	Membrane	V							
30	Tech. Demonstrator	Composite 1	Steel	-	IV	III	IV		III			
31	Tech. Demonstrator	Composite 1	Steel	Weakened case	IV	III	IV		III			
34	Tech. Demonstrator	Composite 1	Steel	Steel case + CF patches	IV	III						
37	RM. Demonstrator	Composite 2	Steel	-	III							
38	Tech. Demonstrator	Composite 2	Steel	Foam A		II	V					
39	Tech. Demonstrator	Composite 2	Steel + CF	-	IV	II	IV		III			
40	Tech. Demonstrator	Composite 2	Steel + CF	Membrane, LTI	V	III			III			
42	Tech. Demonstrator	Composite 2	Steel	Foam A		П	V					
45	Tech. Demonstrator	XLDB 3	Steel + CF	-	V	IV	IV		I			
46	Tech. Demonstrator	XLDB 1	Steel	-	V							
47	RM. Demonstrator	CDB	CFRP		V		V	V		V		
48	RM. Demonstrator	EMCDB	SSL	PID, shear closure		V	V	V		V		
49	RM In Service	Composite	Steel	-	<u>III</u>	1						
50	RM. Demonstrator	Composite	Steel 1	Weakened case, LTI	III	III	B (B (
51	RM. Demonstrator	Composite	Steel 2	Weakened case, LTI	<u> </u>	III	IV	IV				
52	RM In Service	Composite	Alu.	-	<u> </u>		IV					
53	RM In Service	Composite	Alu.	-	<u> </u>		IV		III			
54	RM In Service	CDB	SSL	-	V		V	V				
55	RM In Service	composite	Steel	-		II .	Ш					





Test results & key technology: Propellants

EDB, CDB, CMDB, and new XLDB & GAP propellants give:

- Type V or IV response for FH and SH
- Type V or IV response with adequate barrier or storage configuration for BI, FI and SR [12, 47, 48] but if without this configuration then Type I, II or III for FI, SR & SCJ [2, 9, 21] since they are more sensitive to intense shocks due to NG, explosive fillers and combustion instability suppressant content
 - 1% of refractories in some EDB & CDB propellants increase the FI SDT sensitivity by 500 m/s [9,10]
- NG replaced by less sensitive Nitrate Ester leads to type V or No Reaction for BI [17, 22,]



[54] Type V FH, BI & FI (2530m/s): CDB with refractories



[21] Type IV BI : EDB



[21] Type I SCJ, SR: EDB





[17] Type V, NR: XLDB2



[47] Type V FH, BI, SR & FI (2530m/s): CDB no refractories



[21] Type IV SH: EDB



[22] NR GAP RDX KOA



[17] Type NR: XLDB2





Test results & key technology: Propellants

Composite HTPB propellants give:

- Type V & IV reaction for FH, BI and FI aggressions. Large motors, High Burning Rate propellant or a very strong case can lead to Type III reactions [28,37,49,50,55]
- Type I or II very violent reaction to SH aggression (without any Mitigation Devices) due to AP damage & bulk propellant exothermic reaction. Promising additives (at propellant level for SH) have not been effective in RM's [38, 39, 42, 49, 55]

Composite HTPE propellant give:

Type V response in SH lab tests has not been successful when tested in RM [26, 27]



[14] Type V FH: COMP HTPB



[14] Type V BI: COMP HTPB



[51] Type IV FI 1754 m/s: COMP HTPB



[49] Type I SH: COMP HTPB



[27] Type III & NR HFI : COMP HTPE



[27] Type II SH: COMP HTPE









Test results & key technology: Cases

RM Case main function is to withstand internal pressure during RM operation.

- Case properties have a strong influence on the level of confinement and reaction violence for FH, BI, FI aggressions when EM is ignited, and a moderate influence on RM responses for SH, SR, SCJ aggressions / 28, 37, 49, 50]
- Al, SSL, KOA, CFRP cases lose mechanical properties very quickly under FH & BI aggressions and commonly lead to venting upon ignition of propellant, which is able to burn benignly at atmospheric pressure giving Type V reactions or type IV in case of propulsion, ejections or overpressure for large motor [3, 5,11,13, 23, 52, 53, 54, ...].

Weakened steel cases with an appropriate manufacturing process and grain design, lead to case rupture prior to ignition of propellant for FH [51]



[28] Type III FH: Steel



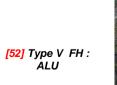


Weakened Steel

[23] Type V FH, BI: SSL



[19] Type V FH, BI: KOA







Test results & key technology: Mitigation devices

Several types of mitigation devices have been developed and tested

- Thermal barriers (Internal and/or external & membrane) delay the reaction and potentially control the case failure mode and decrease the response to a Type V for FH aggression. [24, 25, 29]
- PID and LTI initiate EM at a temperature lower than the threshold of thermal reaction for SH aggression and can improve the RM reaction from a Type I or II to a Type III or IV [5, 20, 23, 27, 48, 50, 51].
- Foam in the inner bore of the charge to avoid SDT or XDT for BI & FI [38, 42].
- LMA, SMA, and active venting systems have been tested at laboratory scale



[24] Type V FH



[38, 42] Type V BI: Steel + Foam



Intumescent Paint expansion



[38, 42] Type V BI foam in bore



Type of foam





2.75" SSL with PID: SH Type V (BWB / WDT91 trial photo)





[5, ,20, 23, 27, 48, 50, 51] PID,





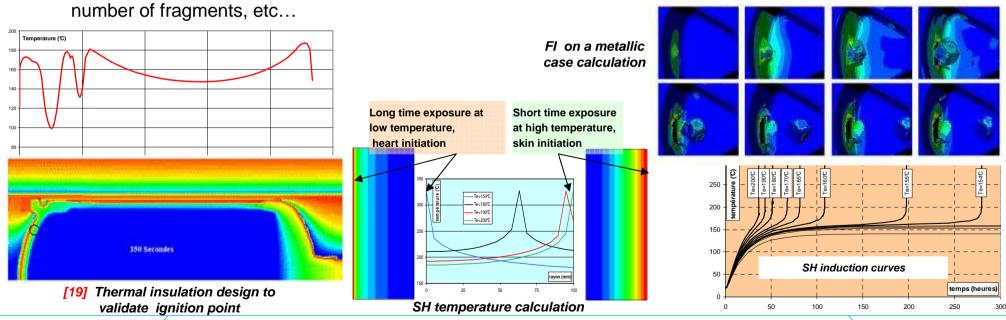
Test results & key technology: Modelling

Modelling of the IM phenomena is conducted for thermal aggressions, but still in preliminary studies for mechanical aggressions

- Will highlight problematic design features and further the design of IM mitigation technology [19, 53]
- Assist in IM trial instrumentation and results analysis (reaction time, temperature state of specimen)
- Requires reliable input data, sometimes difficult to obtain in order to conduct accurate state modelling of the stimuli:
 - Wind, fire, positioning within trial, clamps and fixings, mechanical characteristics, etc...

Challenging to predict the subsequent reaction effects

• EM state under aggression and initiation process, distance of inert and EM projections, overpressure levels,





Synthesis of key Roxel IM technology

- Thermal threat: Fast Heat (FH) & Slow Heat (SH)
 - Case technologies & venting devices to decrease and control burst effects (FH & SH)
 - Thermal barriers to delay reaction and possibly give orientation to a case failure (FH)
 - Pre-ignition of propellants at a temperature lower than the threshold of EM thermal reaction (SH)
 - PID or LTI combined to case venting technology could achieve the best IM response
 - Modelling and simulation of thermal state in RM (FH & SH)
- Mechanical threats: Bullet Impact (BI) & Fragment Impact (FI) Sympathetic Reaction (SR) & Shape Charge Jet (SCJ)
 - Less shock sensitive propellants: low Card Gap Test and High Velocity Shotgun result (> 600m.s⁻¹) and modified propellants (SH)
 - Appropriate storage barriers, case technologies to absorb impact energy & increase venting at EM reaction or disrupt effectively upon impact
 - Internal barrier, foam in the inner bore of the charge
 - Modelling and simulation of mechanical EM state in RM (BI & FI)





Challenges with RM IM response assessment

- During last 20 years IM tests have been conducted in various test centres (SNPE, DGA / CAEPE, UK MoD, and others) and are very often subject to discussions on tests conditions and results interpretation.
- IM trials are not perfect tests, they are very costly with low repeatability
- Even if they are in accordance with STANAG and AOP, test's centre experience, safety requirements, measurements, and of course weather conditions can induce test variabilities.
- The analysis of test results and their interpretation can be subject to discussions giving opportunity to doubt about IM reaction type assessment

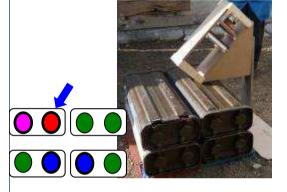




Influence of test conditions

Specimen positions: Distance above fire, Horizontal/Vertical, distance of donor acceptor, SR SCJ configurations

Fuel distance (cm)	30	40	50	60	70
T° (°C)	812	901	935	983	986











Attachments and fixings: Rigidity, dimensions of support, thrust safety devices



[51] Type V FH
CASE DEFORMATION IN
SUPPORTS

[52] Type V? FH SUPPORT BROKEN and PROPELLANT EJECTION AT 15.2 M









Influence of test conditions

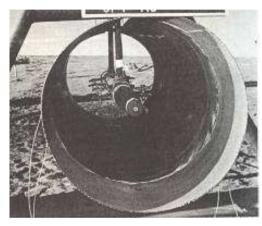
Cell characteristics: Confinement of specimen, protection against ejection & blast pressure



[49, 50, 51] SH HEAVY CELL

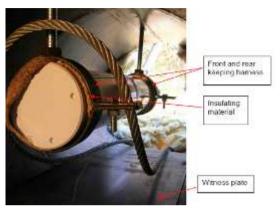


[20] SH LIGHT CELL



SH PROTECTION CELL





[21] SH PROTECTION CELL



[27] SH PROTECTION



Weather conditions: Wind, temperature, rain





Page 15



Influence of test conditions

Characteristics of aggression

- FH: Type & temperature of fuel (fuel, wood, gas)
- HFI: Fragment material, mass & shape (spherical or parallelipedic)
- BI, FI, HFI: Velocities difficult to reach accurately
- BI, FI, HFI: Choice of impact position not discussed
- SH: Heat rate, initial temperature (possibility of 100°C?)
- SCJ: Shape charge type specified in Stanag is not available





FH FUEL AND GAS AGGRESSION

Validity of a test non compliant with Stanag: No test?

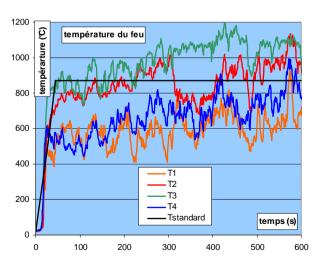
- Temperature and delays, velocity, impact point, heat rate, measurements insufficient or not available
- A clear IM response (I to V) is not really possible for SR: the expected result is "Transmission or No Transmission of Detonation". For example it does not seem possible to justify a Type V or IV reaction



IMPACT NOT COMPLIANT



ALTERNATIVE BLAST PRESSURE MEASUREMENT METHOD "CHALARD BOX"



TEMPERATURES NOT COMPLIANT







STANAG 4439 edition 2 and AOP-39 edition 2 give definitions, threats, IM requirements, test procedures and guidance for interpretation of responses

DECRONCE	MUNITION BI	EHAVIOUR	EFFECTS									
TYPE	ENERGETIC MATERIAL	CASE	BLAST	PROJECTION OF ENERGETIC MATERIALS	PROJECTION OF FRAGMENTS	OTHER						
ı	-Detonation -Supersonic decomposition reaction	-Very fast plastic deformation -Total fragmentation	-Intense shock wave -Damage to neighbouring structures	-All the materials react	-Perforation, plastic deformation or fragmentation of adjacent metal plates.	-Large craters in the ground.						
II	-Partial detonation	-Partial fragmentation + large fragments	-Ditto -Ditto		-Ditto	-Ditto -Proportional to % of detonating material						
Ш	-Fast combustion of confined material (Explosion) -Local pressure build up	confined material -Violent breaking into (Explosion) large fragments		-Blast effect < detonation -Damage to neighbouring structures -Scattering of burning materials -Risk of fire		-Small craters in the ground						
IV	-Combustion/Deflagration -Non-violent pressure release	-Breaks but does not fragment into more than 3 parts -Expulsion of end caps -Gases release through opening	-Blast effect limited to ΔP < 50 mbar at 15 m	-Scattering of materials -Risk of fire	-Expulsion of end caps and large structural parts -No significant damage	-Damage caused by heat and smoke -Propulsion of unattached sample						
v	-Combustion	-Split in a non-violent way -Smooth release of gases -Separation of ends	-Blast effect limited to ΔP < 50 mbar at 5 m	-Energetic materials remain nearby (< 15 m)	-Debris remains in place, except covers -No fragment of more than 79J or more than 150g beyond 15m	-Heat flow < 4 KW/m² at 15 m						

Red = The key parameters subject to discussion during interpretation of test results





Propulsion status changes a type V in Type IV reaction but:

- How is propulsion defined when you get 3 holes (BI or FI)? or measure an axial thrust during a HFI trial without any EM ignition
- Mil Std 2105: "A reaction whereby adequate force is produced to impart flight to the test item in its least restrained configuration"
- French DGA instruction "Réaction qui produit une force suffisante pour provoquer le départ de l'échantillon testé"
- Test centres "Displacement or gas flow through nozzle"





[51] BI Type IV PROPULSION



[27] Type IV; BI PROPULSION NOT IN EVIDENCE SMALL FLOW OF GAS THROUGH NOZZLE







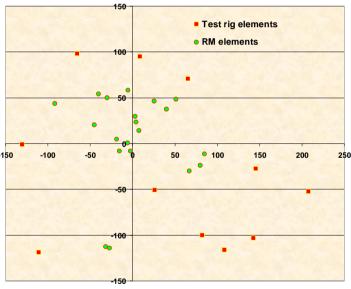


Fragment and energetic material projection distances change a reaction from Type V to IV or III but

- Cartography of fragment position just used for distance (nb & origin, not lethality)
- Ejection of end caps, 3 parts (nozzle), and distance remains a problem for V, IV, III Types
- Origin (EM or Inert) of fragments and their energy is not always clearly identified (video evaluation)
- Scattering of material (risk of fire) is the same for Type III and IV reactions



[28] BI Type III



[27] SH Type II



[53] BI Type IV (VIDEO DISTANCE EVALUATION OF PROPELLANT PIECES PROJECTIONS)





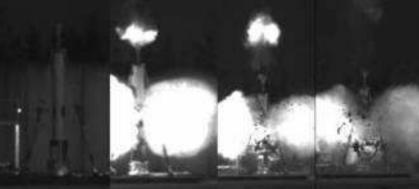
Blast pressure results and the measurement accuracy is influenced by various parameters

- Pressure gauge's positions and any directional or reflection effects
- Validity of threshold of 50 mbar at 5m and 15m

No Reaction statement for FI, HFI

Analysis of a stopped reaction



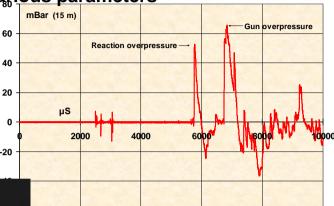


[27] HFI: Type III OR STOPPED REACTION?

TNT equivalent calculation method not specified

- Based on explosive pressure effect
- With TNT % equivalent interpretation for a partial detonation result of EM!

Heat flux never measured and used



Fragment mass 252 g (sphere)
Fragment velocity 1813 m/s
Propellant stops burning
immediately after impact
(More than 85% of the motor mass
recovered)

No Propulsion ? Several fragments

Overpressure 52 mbar at 15 m

\$type III ?





IM RM response assessment conclusions

- Test conditions and interpretation should not lead to discussions
- An IM RM response assessment should always be referenced to an accessible test report which must be seriously analysed even in the case of "no-test" situation.
- To reach an homogeneous and coherent IM response assessment then it seems necessary to ask for an "Expert Committee", able to state independently on the validity of test conditions, and propose the RM IM signature.
- RM should not be considered alone but at the munition level. For example the missile system's reaction of a RM can be changed by the warhead reaction or its configuration standard e.g. packaged system.
- It seems necessary to update STANAG & AOP39 procedures and tables of classification.





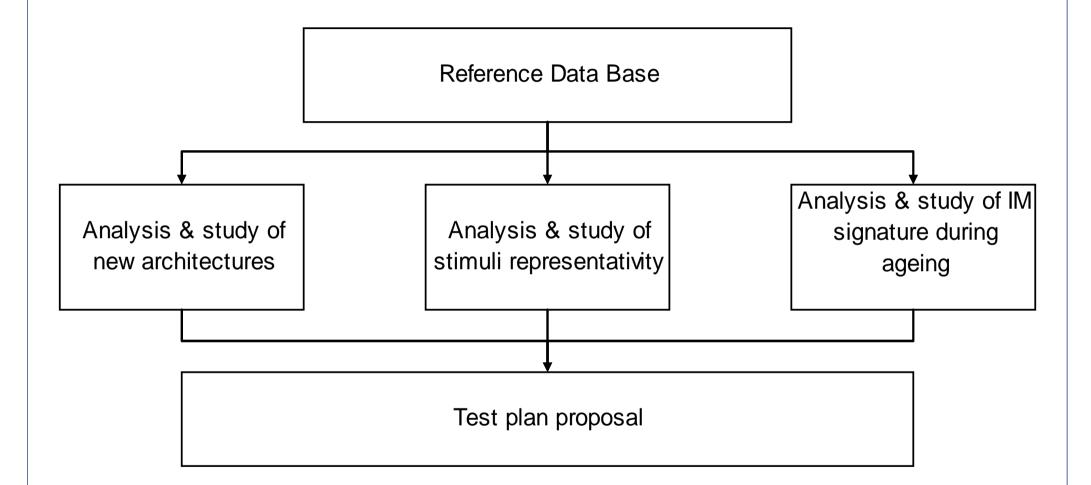
IM technologies gap, new research areas

- Case technology able to create sufficient venting in response to the SH stimulus.
- Improvement of passive PDI & LTI operation reliability.
- Development of acceptable active venting systems for FH & SH in field of smart RM.
- Development of generic, retrofittable, reusable concepts.
- Individual technologies providing full IM mitigation for a multitude of systems.
- Low cost composites cases.
- SCJ IM mitigation.
- Improvement of IM modelling response severity predictive capability.
- Investigate propellants IM ageing on IM response.
- Characterise FI IM response to rocket motor design to develop designer tool.





French MOD IM ARP "APTE" logic







French MOD IM ARP "APTE" test plan

Proposed ARP test plan 3 years work

PROGRAMME	TYPE		YPE CASE			PROPELLANT MITIGATION DI			DEVIO	CE	IM TEST											
DESIGNATION	RM	Demonstrator	Steel	TBD	Composite	SSL	High Burning Rate HTPB	GAP & NEPE	lgniter	Membrane	Foam in bore	Weakness	Intumescent Paint	New	SH	SH* Heat rate	Æ	B	BI* Velocity & caliber	Ή	LFI	SCJ
Ageing Effect	Х														Х		Х	Х			Х	Х
HBR & RM Temperature	Х				Х		Х		X						Х		Х	Х				
New Stimuli	Х				Х		Х		X							Х			Х		Х	Х
New Technology	Х		Х	Х			Х		X					Х	Х		Х	Х				
New Propellant	Х		Χ	Х				Х							Х		Х	Х		Х		
Representativity SCJ		Х	Х				Х	Х														Х
Representativity FH		Х	X				In	ert									Х					





IM UK programmes

- Team Complex Weapons in the UK will require IM new products Loitering Munition (LM), Lightweight Multi-role Missile (LMM), Common Anti-air Modular Missile (CAMM), 50A and Future Air-to-Surface Guided Weapon (Heavy) (FASGW(H))
 - Low cost rocket motor
 - Roxel to address IM technology gaps











- Mechanical IM threats
 - UK-Energetics research programme (Foam bore)
 - FI mitigation techniques
- Thermal IM threats
 - Continuing the recent successful SH IM results (IM Python, IM RRPR, IM HVM, IM Brimstone)
 - Joint Anglo-French programme developing a low cost 2.75-inch IM solution





IM Low Cost Design Methodology

IM mitigation technology: is it an expensive addition?

Customers recognised that IM is a critical requirement. But IM products must be produced at a low cost - Roxel is continuing to develop its low cost IM design methodology.

1. Technology level:

- Current high performing solutions with low cost variants
- Current design features rather than proposing costly replacement solution
 - Roxel's bonded patch technology
 - Future IM technology developed to mitigate a number of IM threats through a single product or design
 - Proposed complete thermal and mechanical IM mitigation.

2. Rocket motor level:

- At component level understanding of the successful IM results previously obtained
 - Through modelling and sub-scale testing
 - Without adding extra mitigation devices as example, the excellent 2530 ms⁻¹ FI response for JCM and Python





IM Low Cost Design Methodology

3. System level:

- THA to identify the most probable and critical system configuration and target <u>ONLY</u> this level to reduce the IM insertion costs to one product
- Establish the whole life costs according to a specified IM level
 - Additional costs & possible financial savings analyse ACB IMEMG or CBAM MSIAC softwares
- Produce technology which mitigates a number of munitions at once or a whole magazine

4. Productionisation level:

- Productionisation can be applied at any of the above levels to reduce the overall IM insertion costs
 - For example a slight modification to the manufacturing tooling to improve the IM capability of a steel case with no additional recurring costs
 - IM improvement from a Type I to III



•

Conclusion

• IM rocket motor technology has progressed significantly due to numerous tests and programmes funded over the last 20 years either by MOD's, missile primes and by Roxel's self funded research.

- However, a technology gap still remains:
 - SH mitigation devices/cases and LTI & PDI reliability
 - FI, SR & SCJ behaviour
 - Ageing influence
- STANAG and AOP need to be updated and improved:
 - IM signature sometimes difficult to establish due to test conditions and interpretation
- New programmes are in progress to improve knowledge and low cost technology.
- Low cost IM solutions are the present challenge for the future.





Acknowledgements & Questions















Any Questions?

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The Centre of Excellence in **Protection, Safety and Information Security**

Performance through Research

PVTT

Accelerated ageing study of low sensitivity PBX formulation - FPX V40

IM & EM Symposium, May 11.-14. 2009

Tucson Arizona







Introduction

Two common ways to achieve enhanced insensitivity properties

Melt Cast Formulations

PBX Formulations

Environmental impact

&

Ageing

Elastic binder matrix together with less sensitive high explosives —— IM properties

Increased cross linking density

Degradation of mechanical properties of binder

Changes in mechanical properties of PBX

Possible changes on sensitivity properties of PBX

To predict these changes occurring during the life cycle, artificial ageing study is included in the qualification test program



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Sample material – FPX V40

FPX V40...

- ...is produced by Forcit Defence
- ...is isocyanate cured HTPB based PBX
- ...has shown very good insensitivity properties
- ...is a multipurpose explosive
- ...is used for example in army engineering charges (charges fulfill the IM requirements)





Experimental

Ageing

- STANAG 4581
 - At 60 °C for 3 and 6 months
 - According to van'T Hoffs rule this represents storage for
 - 10 years at 20 °C or
 - 20 years at 10 °C
 - Samples were wrapped in plastic foil during ageing
 - Outer surfaces were removed before machining the test specimens

Testing

- Pristine and aged samples were tested
- Two test temperatures
 - + 23 °C
 - - 40 °C
- Mechanical test were done with Lloyd LR5k Plus
 - Uniaxial tensile test
 - Compression test
 - Stress relaxations test
- Other tests were included in qualification procedure





Results - Tensile test

Low temperature behavior

- Stress, modulus and even strain increased -> cumulative stress is increased
- Tensile properties were maintained also after ageing

Ageing effect

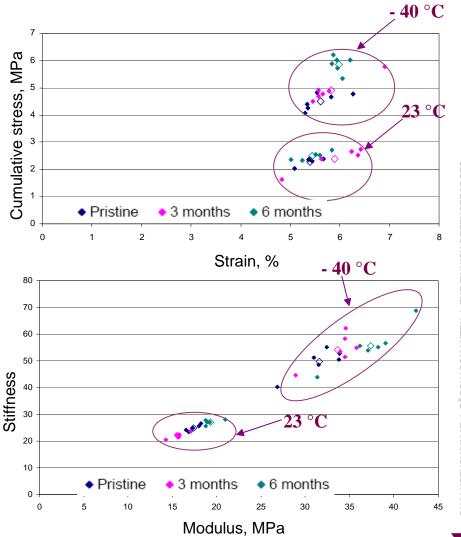
After 3 months

Stress and modulus, thus stiffness was decreased (23 °C)

After 6 months

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Stress, modulus and stiffness were increased and strain remained or even increased -> higher cumulative stress and thus tougher material





The Centre of Excellence in **Protection, Safety and Information Security** Performance through Research

2.6.2009



Results - Compression test

Low temperature behavior

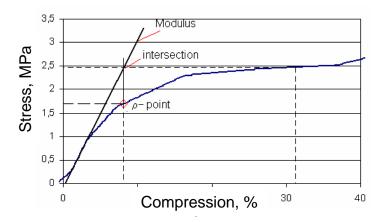
- Remarkable different compression behavior
 - higher compressions
 - stress level is increased
 - linear part lasts longer
 - determined ρ-point moved towards higher compressions
- Toughening behavior was seen in test specimens after compression test – samples were not fractured
- Behavior was consistent with tensile test observations

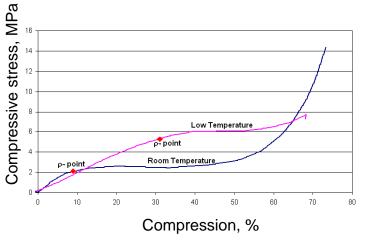
At 23 °C tested samples



At -40 °C tested samples









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Results - Compression test (continues)

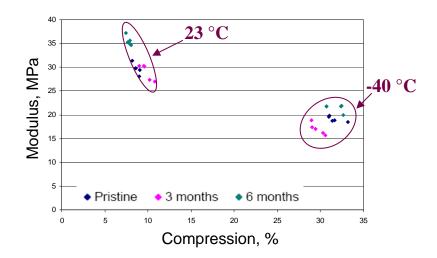
Ageing effect

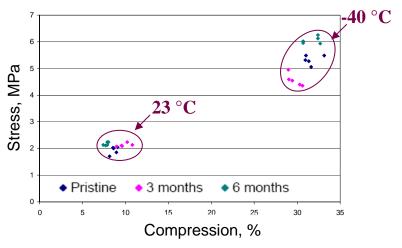
After 3 months

- Decreased modulus
- Slight loose in compression capability was observed at low temperature

After 6 months

- Increased modulus
- No significant change on compression values at room temperature
- Some increase in compression capability at low temperature
- Thought behavior at low temperatures was maintained also after ageing
- ✓ Test results were congruent with tensile test results



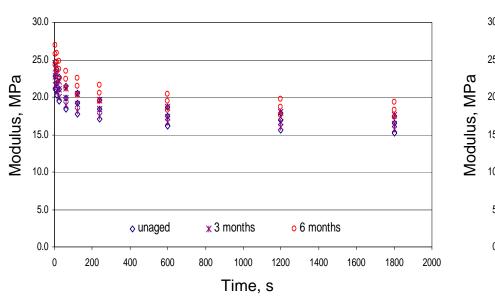


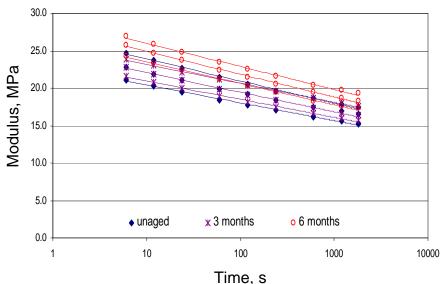






Results - Relaxation test





- Modulus difference between 6-1800 seconds was determined
 - No significant changes can be observed
 - Ageing has a slight effect on relaxation tendency
 - Relaxation tendency was lower samples aged for 3 months
- ✓ Results are congruent with other tests





Conclusions

- Behavior of 3 months aged samples were unexpected
 - Loss of modulus
 - Decreased stress values and stiffness
 - Increased strain values
 - Similar behavior was observed in all conducted tests

Explanation

- Result of recovery or stress relaxation process occurred during short period ageing at temperature which is close to the curing temperature
 - At the curing temperature the internal stresses are at minimum level
 - Relaxation or recovery processes compensates the changes caused by ageing





Conclusions (continues)

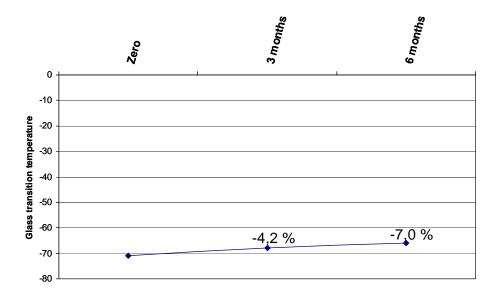
- ✓ Ageing has an effect on mechanical properties although these effects are quite minor
- ✓ During the ageing the sample explosive became tougher and stiffer without losing its elasticity
 - indicating some degree increase in cross linking density but only to such degree that it does not affect strain values.
- ✓ Tendency to relaxation is highest for most aged samples
 - during the initial stretching phase the stiffened structure hinders the movements of molecules and thus relaxation of the polymer
 - chain relaxation occurs slowly in constant strain phase as a function of time.





Correlations to other tests

- Glass Transition Temperature
 - Glass transition temperature (T_g)
 describes the behavior of the
 binder and its structure also
 - T_g was determined with DMA according to STANAG 4515
 - Ageing causes the shift of T_g
 - For aged samples the glass transition occurs at higher temperatures
 - smaller mobility of molecules due to increased cross linking
- ✓ T_g results support the conclusions made based on mechanical tests







Effect on insensitivity properties

 Test program showed that ageing at 60 °C for 6 months has an slight effect on mechanical properties of sample explosives.

Even so:

- No changes in shock sensitivity (LSGT)
- No changes in thermal sensitivity
 - deflagration temperature maintained
 - decomposition temperature maintained
 - slow cook off temperature maintained

Test	Pristine	3 months	6 months
LSGT	31 mm 41 kbar	31 mm 41 kbar	31 mm 41 kbar
Deflagration Temperature	211 °C	213 °C	213 °C
Decomposition Temperature (DSC)	227 °C	226 °C	224 °C
sco	176 °C	172 °C	172 °C





Summary

- ✓ Minor changes in mechanical properties was seen
- ✓ No evidence of change in sensitivity properties
- ✓ Test program however did not take into account the impact sensitivity properties which should be tested in future





Acknowledgements



- o Explosives Technology staff at PVTT
- o M.Sc Matti Muilu
- o Senior Mechanics:
 Jukka Nenonen
 Kari Reinola
 o Forcit Defence





Innovation ... Delivered.

Scale-up of Energetic Nitrate Salts for Insensitive DEMN Formulations

Dr. Sarah A. Headrick



Summary



- Composition B has been used for years in artillery, mortars and bomb fills
 - Contains RDX, TNT and wax
 - Traditional route to TNT generates red water (environmentally unfriendly)
 - Comp B warheads do not meet IM requirements
 - Comp B costs were reasonable historically but modern material is pricier
- ARL developing a series of insensitive melt cast formulations based on DEMN eutectic
 - Designed to replace Comp B and other TNT based formulations
- Two components of DEMN are DETN and EDDN
 - Synthesized on 25 lb scale at ARL
 - 500 lb of each synthesized by ATK in a single month
 - Success resulting from a clear understanding of customer needs, high level of technical expertise and the best facilities
 - ATK working to scale to manufacturing levels

DEMN formulation: an excellent Comp B replacement

DEMN Formulation Invented by ARL



A premier aerospace and defense company

DEMN - Nitrate Salt Based Eutectic

- Nitrate Salts (EDDN and DETN)
 - Easily manufactured at high yield
 - Low cost
- Low melt point allows for melt cast within existing LAP facilities
- Excellent casting properties with minimal shrinkage

Development of DEMN Formulation

- Conventional Explosive Additives
- Tailorable Sensitivity and Performance
- Replaces TNT-based fills which currently fail most (or all) IM tests
- Maintains or improves performance requirements of TNT-based fills



Hot Stage Micrograph Fusion Slide



DEMN Chips

DEMN: an economical and versatile IM explosive formulation

DEMN IM Demonstration and Future Efforts



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Explosive	BI	FI	sco	FCO	SD	SCJI
TNT	IV	IV	Ш	Ш	-	1
DEMN-III J	IV	V	V	V	Ш	(F)

BI - Bullet Impact

FI – Fragment Impact

SCO – Slow Cookoff

FCO - Fast Cookoff

SD – Sympathetic Detonation

SCJI –Shaped Charge Jet Impact

I-Detonation

II-Partial Detonation

III-Explosion

IV-Deflagration

V-Burn

(F)- Assumed Fail

Future DEMN Applications

- Comp B for mortar applications
- Octol analog for high performance applications
- Tritonal analog for general purpose bombs



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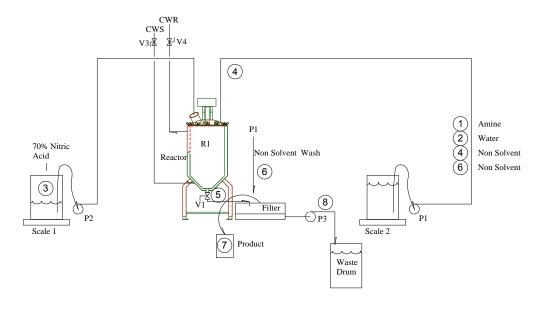


DETN:

$$H_2N$$
 H_2^{+} 3 HNO₃ H_3^{+} H_3N H_3^{+} H_3^{-} H

EDDN:

$$H_2N$$
 NH_2 + 2 HNO_3 $O_3N^{-+}H_3N$ $NH_3^{+-}NO_3$



Acid/base neutralization from affordable starting materials

DETN Reaction Yields



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ARL DETN Reactions:

Rxn#	Batch Size	Yield
1	27.82 lb	99%
2	27.82 lb	97%
3	27.82 lb	97%
4	27.82 lb	97%
5	27.82 lb	98%
6	27.82 lb	98%
7	27.82 lb	97%

ATK DETN Reactions:

Rxn #	DSC Melt	Rxn sol'n pH	Batch Size	Yield*
1	150.8 °C	3.70	40 lb	98%
2	151.5	3.60	40 lb	101%
3	151.2	4.15	52 lb	95%
4	152.4	2.12	104 lb	100%
5	152.0	4.13	157 lb	97%
6	151.8	4.27	157 lb	100%

^{*}Yields based on dry weights calculated from acid, solvent and water content analyses.

Large scale reaction yields in line with ARL results

- Slightly higher than small scale as is expected
- Reproducible

DSC melt consistent with specification of 151 ± 2 °C

- All values between 150.8 and 152.4 °C
- No variation in purity with variations in pH of reaction solution

High yields, high purity, robust process

EDDN Reaction Yields



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ARL EDDN Reactions:

Rxn#	Batch Size	Yield
1	27.81 lb	90%
2	27.81 lb	88%
3	27.81 lb	90%
4	27.81 lb	93%
5	27.81 lb	92%
6	27.81 lb	90%
7	27.81 lb	93%
8	27.81 lb	93%

ATK EDDN Reactions:

Rxn#	DSC Melt	Rxn sol'n pH	Batch Size	Yield*
1	187.6 °C	5.98	49 lb	83%
2	188.2 °C	4.92	65 lb	85%
3	187.9 °C	6.14	104 lb	81%
4	188.1 °C	6.10	157 lb	90%
5	187.9 °C	6.29	157 lb	88%
6	188.2 °C	5.11	65 lb	98%

^{*}Yields based on dry weights calculated from acid, solvent and water content analyses.

- DSC melt consistent with specification of 188 ± 2 °C
 - All values between 187.6 °C and 188.2 °C
 - No variation in purity with variations in reaction solution pH
- Large scale reaction yields in line with ARL results
 - Slightly lower than small scale values as some material stuck to reactor walls
 - Upon further scale up, this material can be recovered

Reproducible, high yielding and robust

Future Pilot Scale Synthesis



A premier aerospace and defense company

- Salts can be synthesized in AES's new pilot plant
 - Built in 2008
 - Designed for manufacture of specialty materials
 - Explosive and inert
 - Air permitted
 - Sited for 10,000 lbs of explosive
 - 2 L to 100 gallon capacity reactors
 - Flexible configuration
 - Support buildings for additional storage
 - Conductive flooring throughout





ATK Pilot Plant perfect for DEMN salts

Manufacturing Capability at Flexible Energetics Facility



A premier aerospace and defense company

 Future manufacturing of salts to be completed in ATK's Flexible Energetics Facility (FEF)

- Sited for large scale production
- \$20M+ investment by ATK





ATK FEF for large scale production

Conclusions and Future Work



A premier aerospace and defense company

- DEMN formulation an excellent, versatile IM explosive formulation
 - Multiple future applications: TNT and Comp B, Octol and Tritonal replacement
- DEMN salts generated affordably and efficiently
 - Uncomplicated, safe chemical process
 - Low cost
 - Use of the best team (ARL and ATK), facilities and process yielded success
- Several improvements to investigate in the future
 - Possible generation of both salts simultaneously
 - Elimination of non-solvent used for crystallization
 - Recovery of material plated on walls of reactor to increase yield in EDDN reaction

DEMN formulation: versatile, economical IM solution

A premier aerospace and defense company

Dr. Brian Roos for technical input and funding

Gene Johnston, Brooks Fry, Dr. Steve Velarde, Dr. Andrew Sanderson and Dr. Steve Ritchie for technical input and assistance

Temperature Independent Gun Propellants Based On NC And DNDA For IM Ammunition

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2009 Insensitive Munitions and Energetic Materials Technology Symposium

May 11 - 14, 2009

Tucson, Az, U.S.A.





Content

- Introduction
- Processing Technology
- ♦ Low Temperature Coefficient (LTC) Propellants
 - Temperature Behaviour, Closed Vessel Results
 - Characteristics of the Propellant Components
- Propellant Performance, Safety & Sensitivity Data
 - Long Term Storage Stability
 - Influence of the Crystalline Components
 - IM Characteristic of the Propellant
 - Shaped Charge Tests
 - Erosivity
- Gun Firing in different Calibers
- ♦ PELE Cartridge
- Results & Conclusion





Introduction

Since approx. 100 years are known the Nitrocellulose Propellants

Self - Ignition Temperature ~ 175 °C

Also the Multi Base Propellants like SCDB and EI, ECL Propellants are giving the Self - Ignition at ~ 175 °C

Nitrocellulose Propellants based on DNDA and RDX the LTC Propellants are showing

First Generation

Self - Ignition Temperature 200 - 210 °C

Second Generation

Self - Ignition Temperature > 220 °C (Eurofighter Propellant etc.)





Processing Technology for Insensitive Gun Propellants based on DNDA

Continuous Process

- Shear Roll Mill
- Twin Screw Extruder (TSE) ZSK 58E





Batch Process

- Kneader / Mixer
- Rampress









Shear Roll Mill (Continuous Process)





DNDA Gun Propellants

- RDX (or FOX-7, FOX-12)
- Binder, Nitrocellulose
- DNDA Plasticizer
- * Plasticizer mixed into the Propellant Dough

NO SURFACE COATING

- energy density adaptable
- ◆ flame temperature approx. 500 K lower compared to NC Propellants

Formulation	Impetus (J/g)	Flame Temp (K)	Mw (g∕mole)
A	1080	2540	19.4
В	1180	2910	20.8
C	1300	3390	21.6



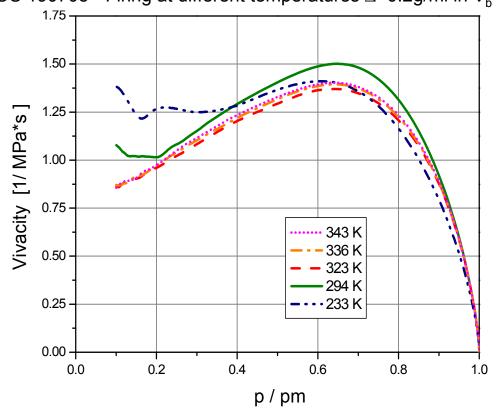


Closed Vessel Behaviour of LTC Propellants

Vivacity of Gun Propellant based on DNDA

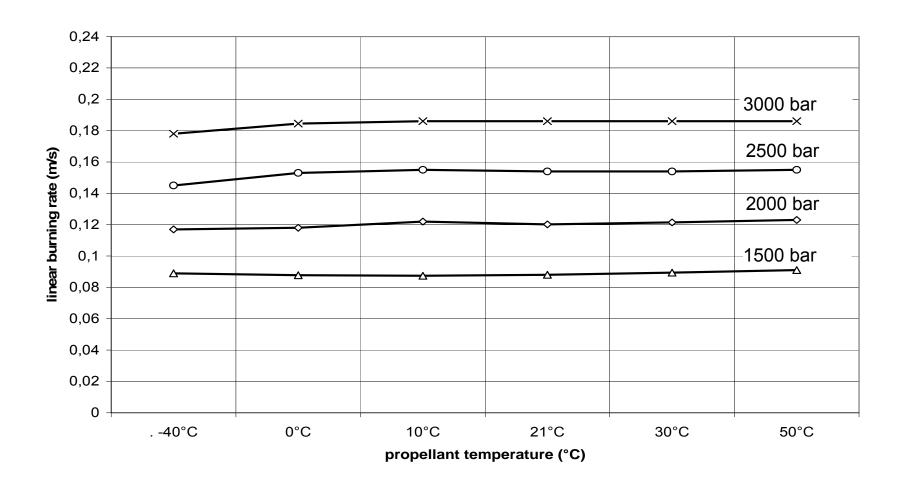
Range -40 °C till +70 °C

LOS 190705 - Firing at different temperatures Δ =0.2g/ml in V_b=310ml





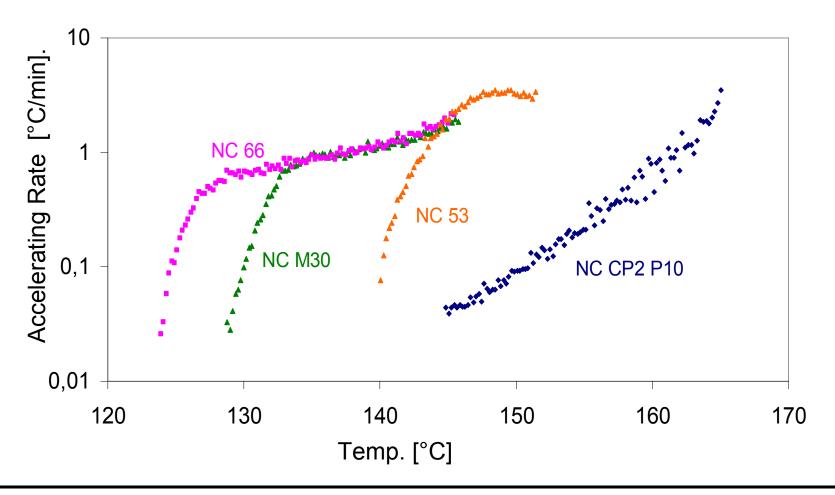
Linear burning rate of LTC Propellants at different pressures







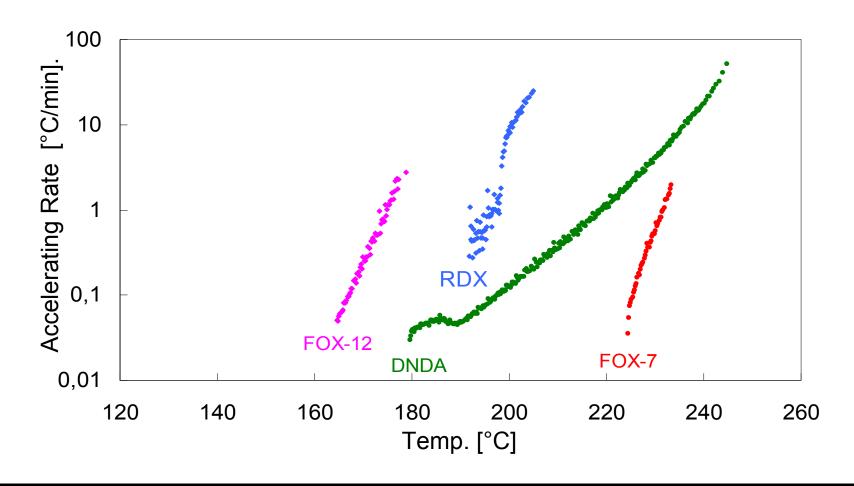
ARC Measurement of several Nitrocellulose (NC) Types





N/1...

ARC Measurements of RDX, FOX-12 and DNDA

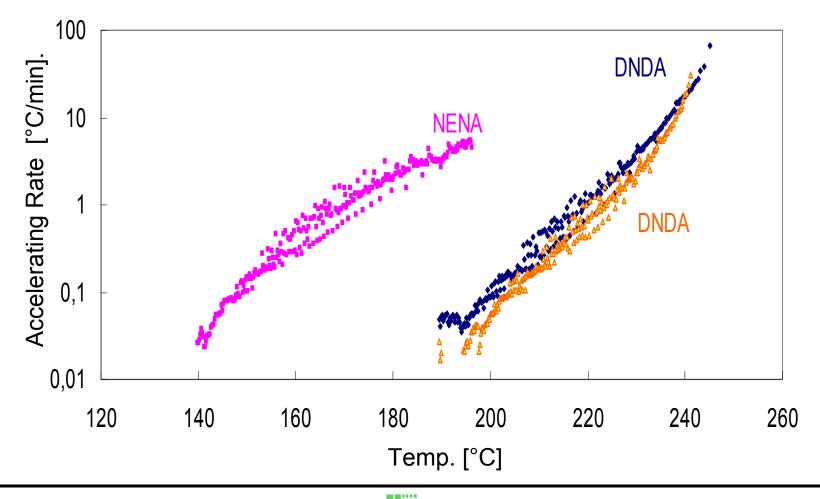






NA...

ARC DNDA-5,7 compared with NENA



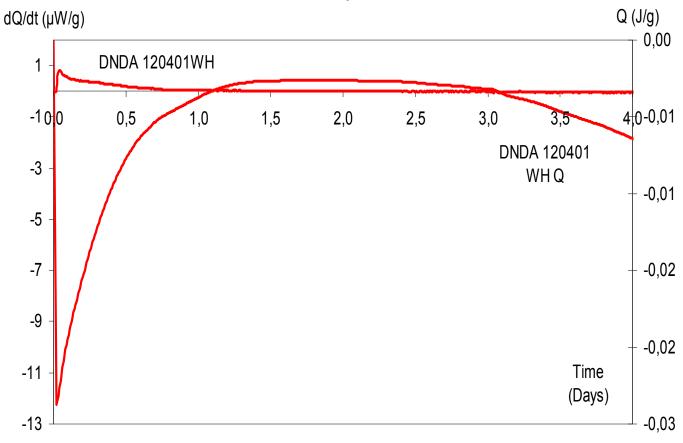




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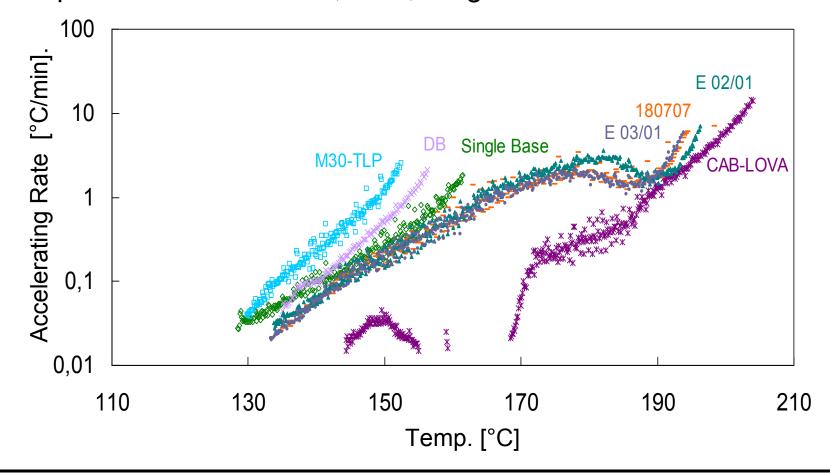
Microcalorimeter Result of DNDA-5,7 Endothermic Behaviour







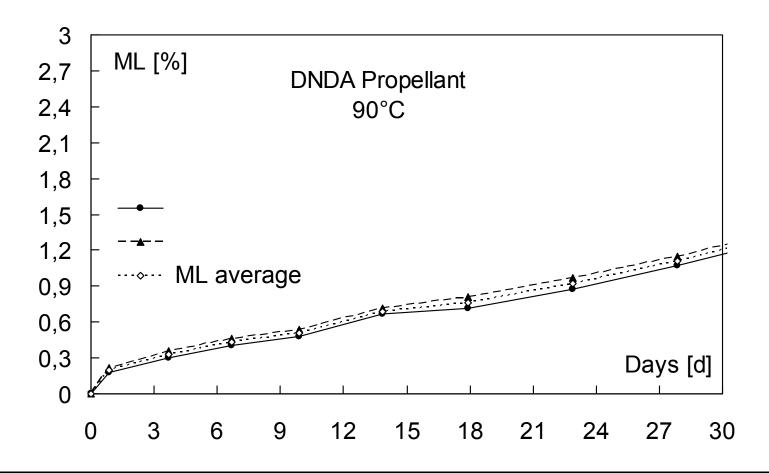
ARC
Accelerating Rate Investigations of DNDA - Propellants
compared with CAB-Lova, M30, Single Base and Double Base





Long - Term Storage Stability at 90 °C

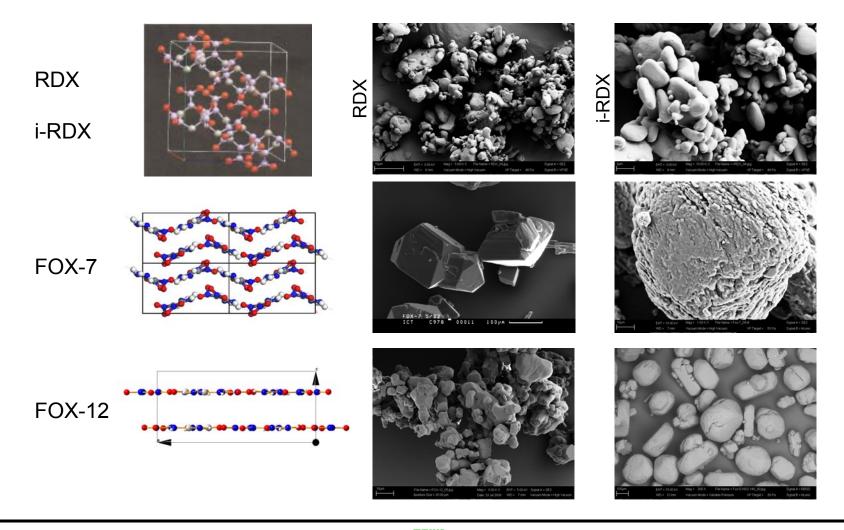
Mass - Loss over Time





NA..

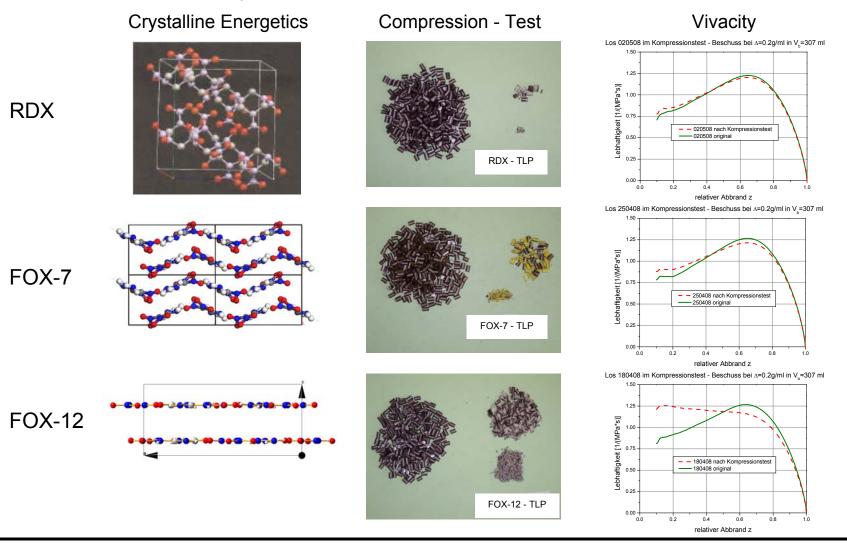
Pictures of RDX, FOX-7, FOX-12







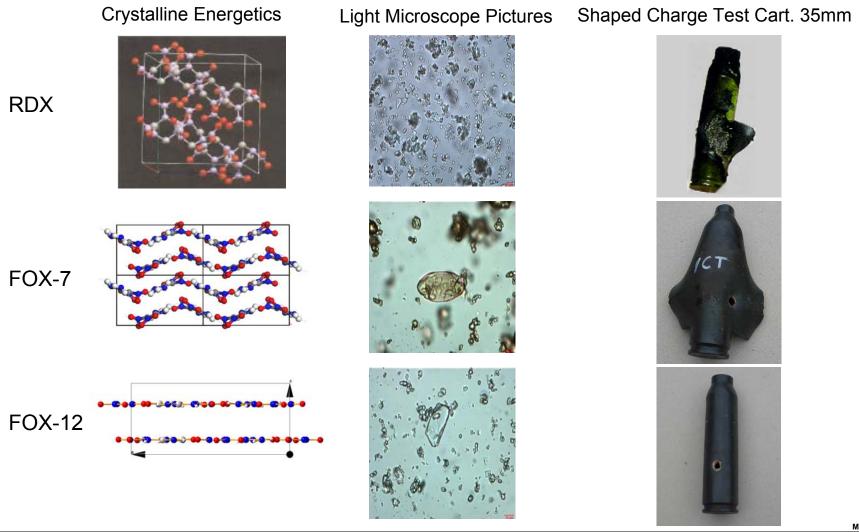
Influence of the Crystalline Components onto Compression Test





Mue

Influence of the Crystalline Components onto Shaped Charge Test







Shaped Charge Tests

DNDA Propellant ICT 1 (RDX), ICT 20 (i-RDX)



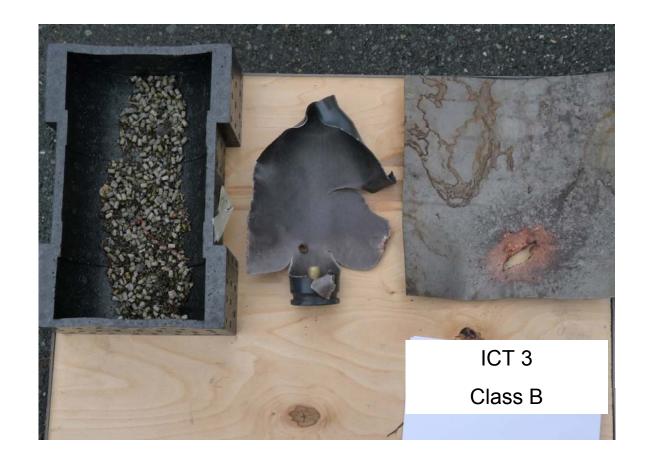
Class A Class A





Shaped Charge Test

DNDA Propellant ICT 3, Class B Test Result





Shaped Charge Test

DNDA Propellant ICT 23, Class A Test Result





Sensitivity Data of different DNDA - Propellants

	FOX-12 Prop.	RDX Prop.	RDX Prop. ICT 1	FOX-7 Prop ICT 23	i-RDX Prop. ICT 20	RDX Prop. mod. DNDA ICT 3
Reaktion Class Shaped Charge Test 35 mm cal.	O no Reaction	Α	Α	Α	Α	В
Friction Sensitivity [N]	240	290	288	252	240	240
Impact Sensitivity [Nm]	6,0	6,5	6,0	7,5	6,0	5,0
Self-Ignition Temp. [°C]	~ 170 *	> 220 *	~ 220	~ 200	~ 216	~ 219
1" Detonation Tube	* no Detonation					
MG 50 /12.7 mm cal.	*	*	IM Reaction Type 5 (MIL – STD 2105 B)			

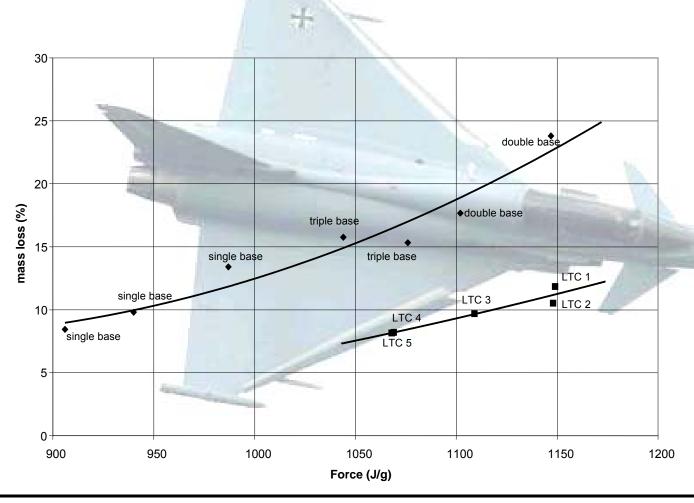
* WIWEB Results







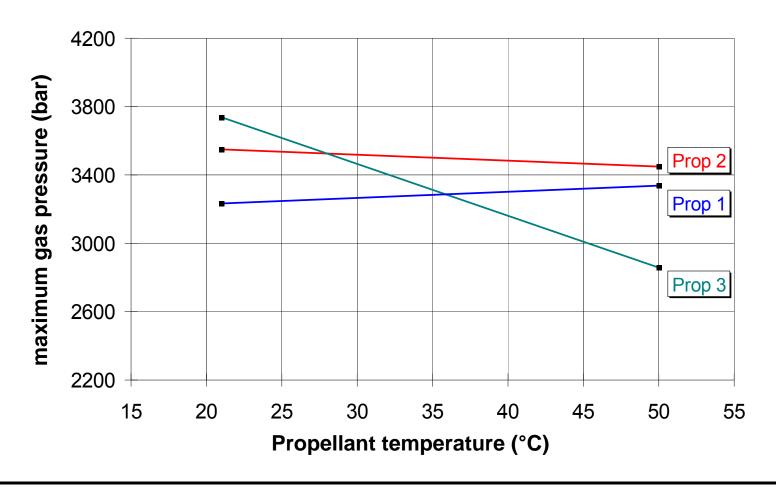
Erosivity of LTC Propellants and Conventional Propellants





Mue

40 mm cal. Gun Firing Tests of 3 LTC Propellants based on DNDA, NC, RDX





Test Firing Gun 40 mm cal.

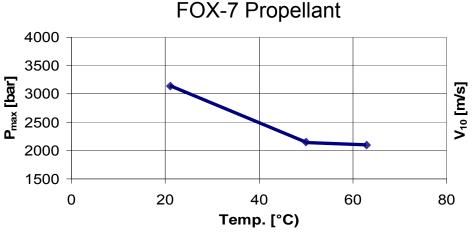
Propellant based on Fox-7, NC, DNDA-5,7

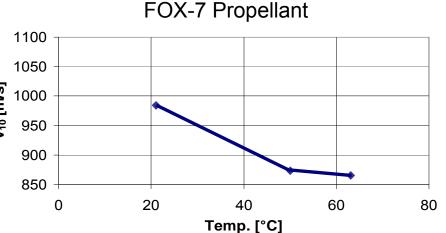
gas pressure vs temp.

muzzle velocity vs temp.

40 mm cal. L70, Los 080308,

40 mm cal. L70, Los 080308,







Test Firing Gun 40 mm cal.

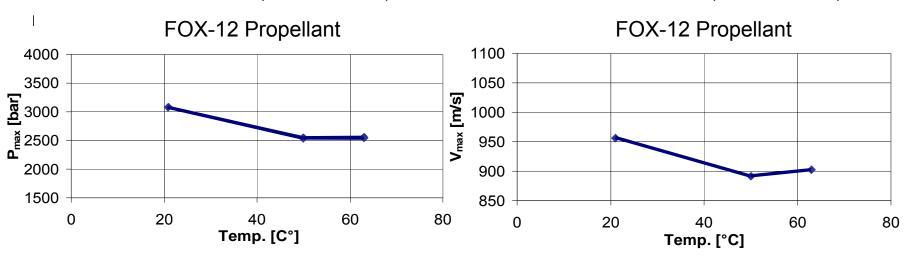
Propellant based on FOX-12, NC, DNDA-5,7

gas pressure vs temp.

muzzle velocity vs temp.

40 mm cal. L70, Los 140108,

40 mm cal. L70, Los 140108,



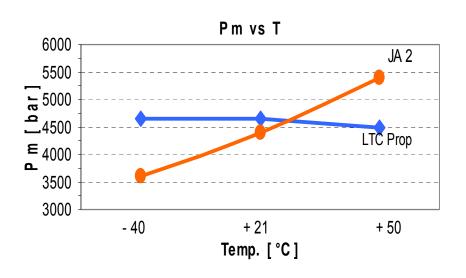


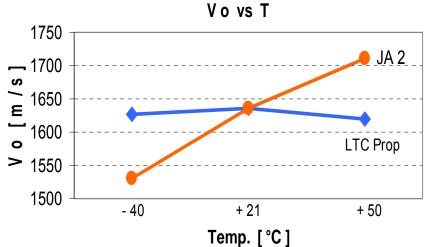
Test Firing in 75 mm cal. Model Gun (Diehl BGT)

Optimized propellant for firing at 21°C, RDX, DNDA based

gas pressure vs temp.

muzzle velocity vs temp.





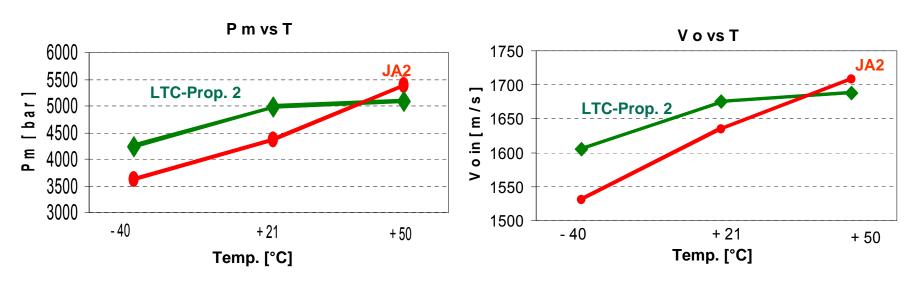


Test Firing in 75 mm cal. Model Gun (Diehl BGT)

Performance optimized propellant, RDX, DNDA based

gas pressure vs temp.

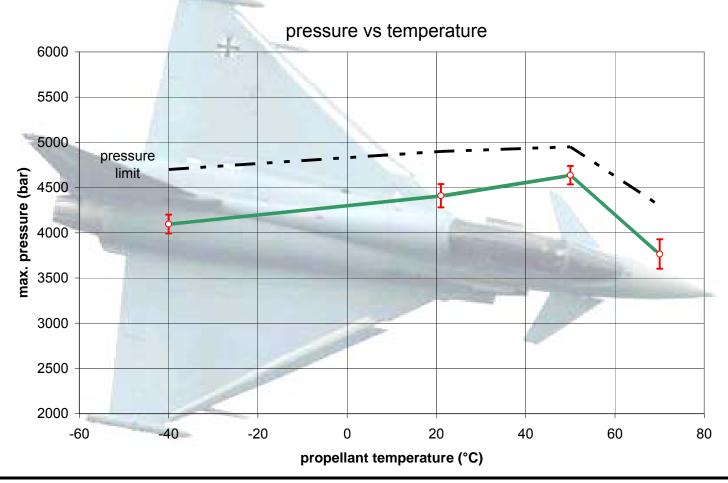
muzzle velocity vs temp.





EF Propellant

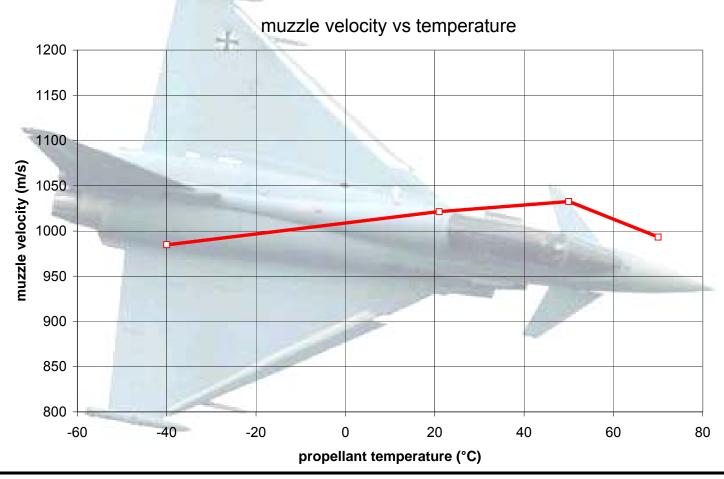
Gun Firing 27 mm cal. Eurofighter





EF Propellant

Gun Firing 27 mm cal. Eurofighter







EF Propellant 27 mm cal. Eurofighter PELE - Cartridge

Combustion Temperature 2900 K

Gun Erosion like Single Base Propellant

Force 1140 J/g

Ignition Temperature > 220 °C

Cook - off Cartridge 27 mm cal.

27 mm Gun Tube Mauser, MATE (Mauser)

Q 5560 (Ref. Prop.) 125 °C 3,5 h Ignition

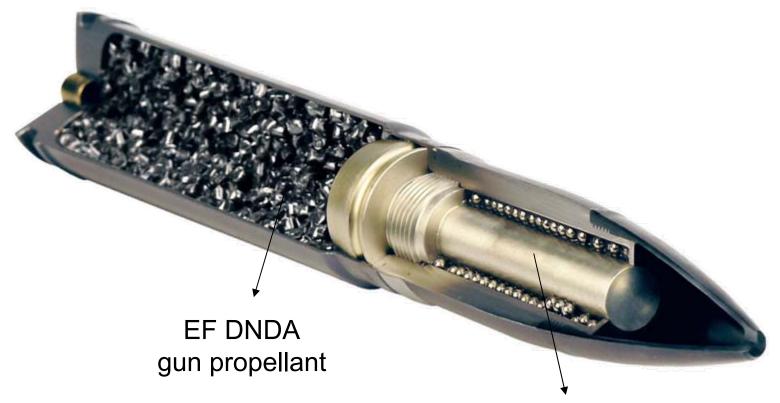
EF - Propellant 125 °C 8,5 h No Ignition





PELE Cartridge 27 mm cal.

PELE = Penetrator with Enhanced Lateral Efficiency



PELE® projectile DM 83 and DM 93 (with tracer)







Results & Conclusion

- ◆ LTC Propellants based on DNDA-5,7 and RDX for a wide Caliber Range
- ◆ Excellent Shaped Charge Test Results (Reaction Class A)
- ♦ High Self-Ignition Temperature > 220 °C
- Insensitive, Reaction Type 5 (MIL STD 2105 B)
 IM Characteristic
 MG 12.7 mm cal. firing on Steel Tube with propellant
- Excellent Long-Term Stability
- ◆ Low Combustion Temperature at High Force and Low Gun Tube Erosion
- ♦ Less Sensitive in Hot Gun Tube (MATE)
- ◆ Propellant Charge for Eurofighter Gun, 27 mm cal. PELE Cartridge





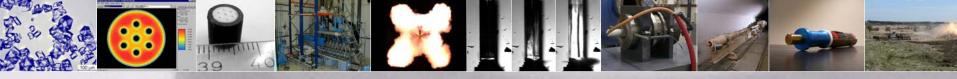
Experimental set-up and results of the process of co-extruded perforated gun propellants

Martijn Zebregs, Chris van Driel martijn.zebregs@tno.nl

TNO | Knowledge for business



TNO Defence, Security and Safety - Protection, Munitions and Weapons - Energetic Materials



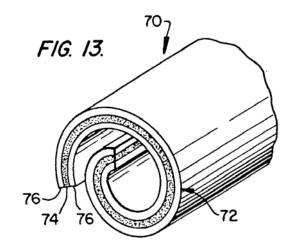
Introduction

- Co-layered gun propellants advantages and difficulties
- Performance characteristics
- Co-extrusion of gun propellants at TNO
 - Experimental set-up
 - Development steps in recent years
 - Burning characteristics of 1-perf co-extruded co-layered propellant
- Future developments
- Conclusive remarks

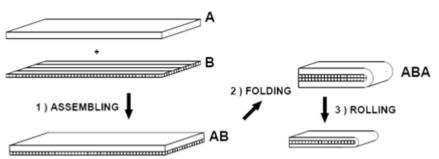


Co-layered propellants

- US Patent 4581998 (1986) A.W. Horst et al.
- Advantage: improvement of gun performance by enlargement of the impulse on the projectile



Ritter ICT 2007
 Manufacture:



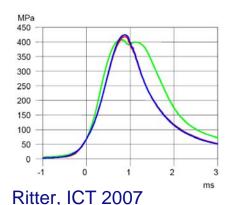
- Disadvantage:
 'The time-consuming manufacturi
 - 'The time-consuming manufacturing of assembled propellant sheets proved to be a difficult task.'
 - TNO's approach: co-extrusion
 - → with proper die design easy manufacturing (not labour intensive and excellent geometries in one step)



Co-layered propellants

Advantages

- Increased performance
- High progressivity of co-extruded 0- and 1-perf grains
- Decreased erosivity of high energy propellants
- Increased ignition behaviour (e.g. LOVA propellants)



(note: not multi-perforated grains!)

Notes

- Increased performance of sheet propellants is comparable to the performance of regular granular multi-perforated propellant
- Variations in layer thickness may result in increased dispersion of V₀
- Contrary to co-layered sheet propellants, co-extruded propellants provide wide variation in geometries, implying a larger number of possible applications

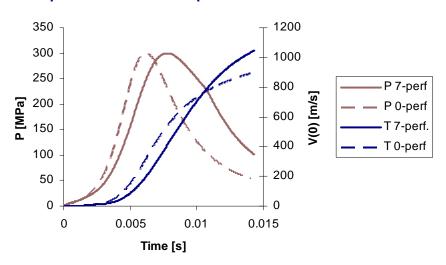




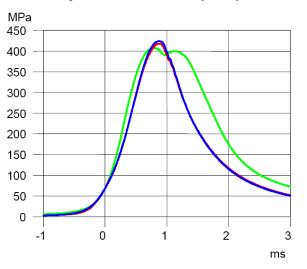
Co-layered propellants

Examples of simulated performance effects

7-perf versus 0-perf



co-layered sheet propellant

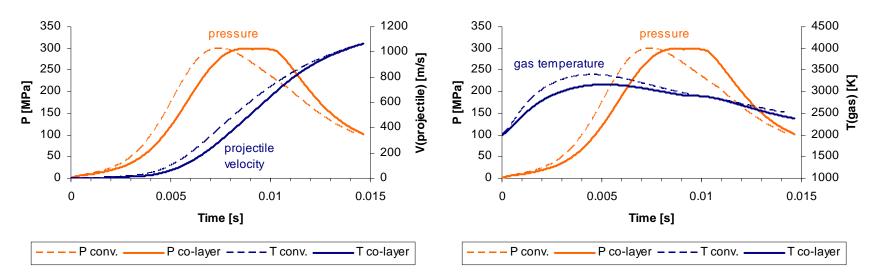


Ritter, ICT 2007

Performance characteristics

Examples of simulated performance effects

7-perf;
$$T_f(core) = 3515 \text{ K}$$
; $T_f(layer) = 3170 \text{ K}$ factor burning rates = 1.5



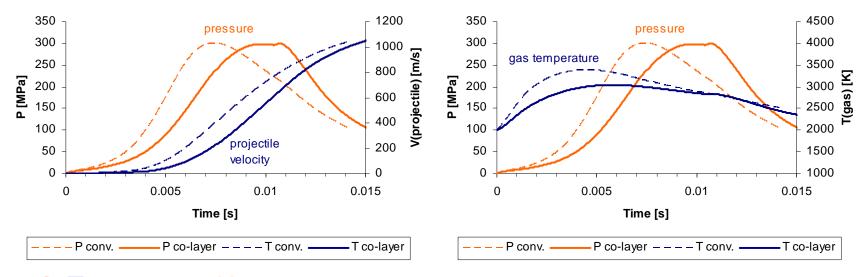
→ T_{max} = 3165 K
= 3385 K without 'cool' outer layer



Performance characteristics

Examples of simulated performance effects

7-perf;
$$T_f(core) = 3515 \text{ K}$$
; $T_f(layer) = 2900 \text{ K}$ factor burning rates = 2



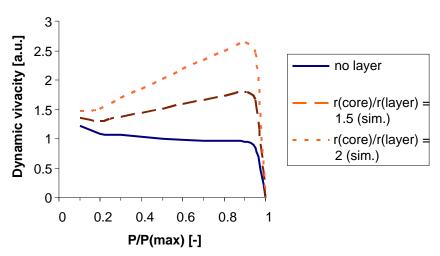
Higher charge densities -> further performance improvement

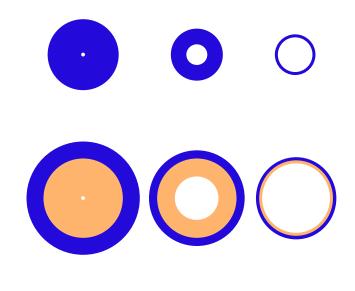


Performance characteristics

Examples of simulated performance effects

Dynamic vivacity 1-perf grain: (both layers intact until Z = 100%)



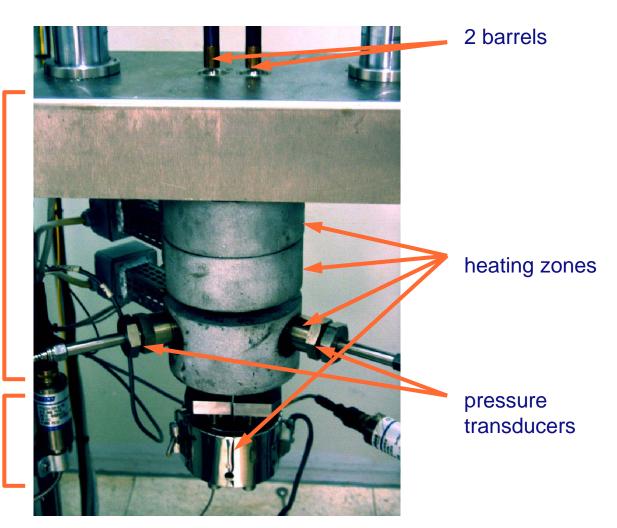


- increased progressivity, even without double peak; 'low' (usual) pressure exponent
- → with smaller outer layer: progressive + double peak in P-time curve
- → large grains (applicable for both medium and large calibre)



double barrel capillary rheometer

(co-)extrusion block



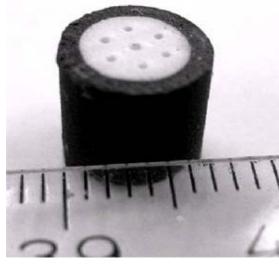
First attempts (2005-2006):

- Non-perforated co-extruded propellant
- 'Self-encapsulation' is theoretically possible for a large viscosity difference (factor 2.5), but appears to fail
- Improper die design leads to slip, resulting in a 'rope of beads'
- Experiments resulted in good insight in the problem of co-extrusion





- Improved die-design using special simulation software in 2007 (applying available knowledge from polymer processing)
- First die for demonstration purposes
 - This die is restricted to equal mass flows of outer layer and core (application with two-barrel capillary rheometer facility)
 - Perforation positions not optimised for 7-perf geometry (depend on propellant compositions and burning rates)



Co-extruded LOVA propellant



Co-extruded DB propellant



Bond integrity at high pressures:

- → Closed vessel tests with DB single-perforated co-extruded grains
- Manufacturing:
 - Excellent distribution of both layers
 - Excellent bonding



6.8 mm

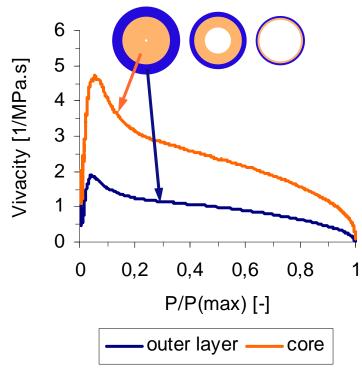


Bond integrity at high pressures:

→ Closed vessel tests with DB single-perforated co-extruded grains

Determination burning rates:

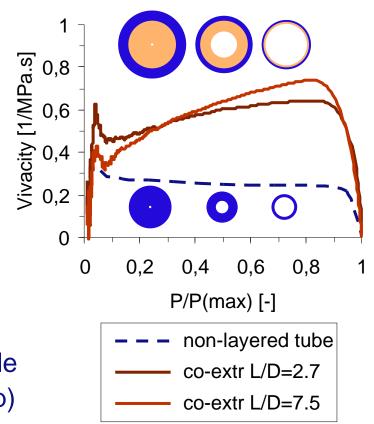
- non-perforated grains
 - L = 10 mm
 - D = 1.45 mm
 - \rightarrow burning rate ratio ≈ 2.3
- Layer thickness ratio ≈ burning rate ratio
 - → both layers are consumed at the same time (no vivacity jump)





Bond integrity at high pressures:

- → Closed vessel tests with DB single-perforated co-extruded grains
- Non-layered tube: neutral burning behaviour
- Layered propellant: progressive Progressivity determined by:
 - burning rate ratio
 - L/D ratio
- $P_{max} = 260 \text{ MPa}$: good bonding
- Extra performance increase possible for thinner outer layer (vivacity jump)

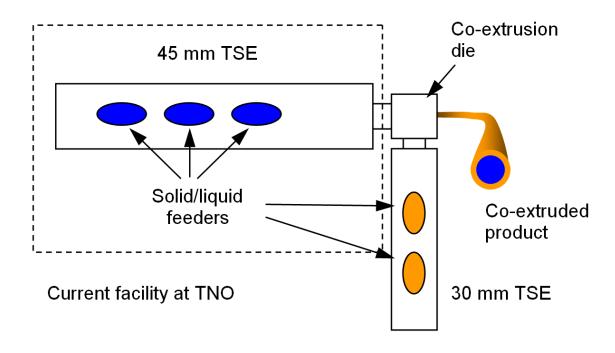




Future developments

Continuous co-extrusion

- Current twin-screw co-rotating extruder: 45 mm; 5 15 kg/h
- Second extruder: 30 mm; 1.5 5 kg/h
- Outer layer: ~10 50% of total strand volume





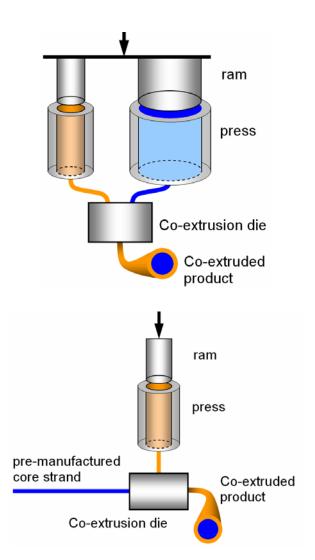
Future developments

Double ram press

- Mass flow ratio of both layers is always constant
- Excellent reproducibility
- Flow outer layer is adjustable, which creates a variable process for several applications

Alternative ram extrusion set-up

- Well controllable process
- Inner and outer layer can be variable (i.e. composition and size)
- No dramatic change of facilities





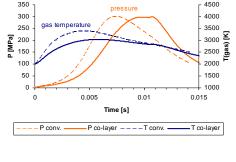
Conclusions

Co-extrusion

- Relatively easy, one-step manufacturing process
- High progressivity / increased performance
- Decreased erosivity of high energy propellants (– 300 K or more)
- Other advantages (improved ignition behaviour, IM, ...)
- Several grain geometries possible
 - non-/ single-/ multi-perforated
 - wide range of applications / calibres

Experiments

- Successful application of co-extrusion technique
- Excellent bonding between core and outer layer







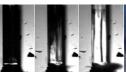


























Development of Cast Cure Explosives for Comp B Replacement

Prepared by:

Robert Hatch, Paul Braithwaite, Nathan Seidner, and Jim Wright ATK Launch Systems

May 11-14, 2009

NDIA IM/EM Technology Symposium, Tucson, AZ



Outline



Two cast cure formulations developed:

- Formulation DLE-C054 (RDX, NTO, HTPB binder)
- Formulation DLE-C055 (RDX, TEX, HTPB binder)

Formulation Characterization

- Formulation and processing features
- Small scale sensitivity
- Subscale performance testing
- Subscale Insensitive Munitions testing

Background



A replacement explosive for Comp B must meet the following objectives:

- Low Cost
- High Performance
- Castable, with good processing characteristics
- Respond well to IM threats of impact, cookoff, and sympathetic detonation

Potential advantages of cast cure versus melt pour formulations:

- Problems with volume changes due to phase changes avoided
- Rubbery nature of binder provides damage resistance and improves response to impact events
- Cast cure charges usually contain low numbers of defects that can increase shock sensitivity
- Proven IM capabilities demonstrated in formulations such as PBXN-110 and PBXN-109

DLE-C054 Formulation and Processing



A premier aerospace and defense company

Formulation

- HTPB binder system
- 88% Solids
 - Coarse RDX
 - Coarse NTO (3-nitro-1,2,4-triazal-5-one)
 - Fine RDX

Processing

- Viscosity minimized by adjusting ratio of coarse and fine RDX
- Excellent processing with end-of-mix viscosities from 7-12 kp
- Material flows easily through slit or hole plate when casting

DLE-C054 Scale Up



- Made in ¼ pint, pint, 1-gallon, and 5-gallon mix sizes
- Scale up was straightforward with just slightly longer mix times at larger mix sizes
- End-of-mix viscosity and processing was identical at each mix size
- Expected to scale easily to production 600-gallon mixers
- ATK Launch Systems has mix facilities capable of producing millions of pounds per year

DLE-C054 Small Scale Sensitivity



Excellent sensitivity

DLE-C054 Sensitivity					
	Uncured Cured Class 5 RDX				
ABL Impact (cm) – TIL	41	51	1.8		
ABL Friction (lbs) – TIL	≥800 @ 8 ft/s	≥800 @ 8 ft/s	25 @ 6 ft/s		
ABL ESD (J) - TIL	5.7	0.133	0.025		
DSC Onset (°C)	221	216	219		



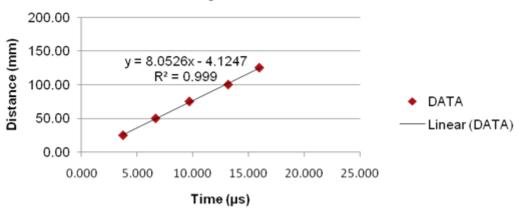
Two dent/rate tests performed

LSGT Hardware (13.97 cm long by 3.65 cm diameter charge)

Excellent performance

Detonation velocity = 8.0 km/s (Comp B = 7.9 km/s)

Velocity Measurement



Dent Depth (DLE-C054)	Dent Depth (Comp B)	Percentage of Comp B	
0.398"	0.433"	92%	



DLE-C054 VCCT Testing



Variable Confinement Cookoff Testing Performed

Heat rate = 6°F/hr

VCCT				
Wall Thickness (in.)	Reaction Temperature (°F)	Result		
0.030	342	burn		
0.045	342	pressure rupture		
0.075	341	pressure rupture		
0.090	341	pressure rupture		
0.120	341	deflagration		

VCCT at heavy 0.12 inch confinement

- •steel sleeve in one piece
- no fragmentation

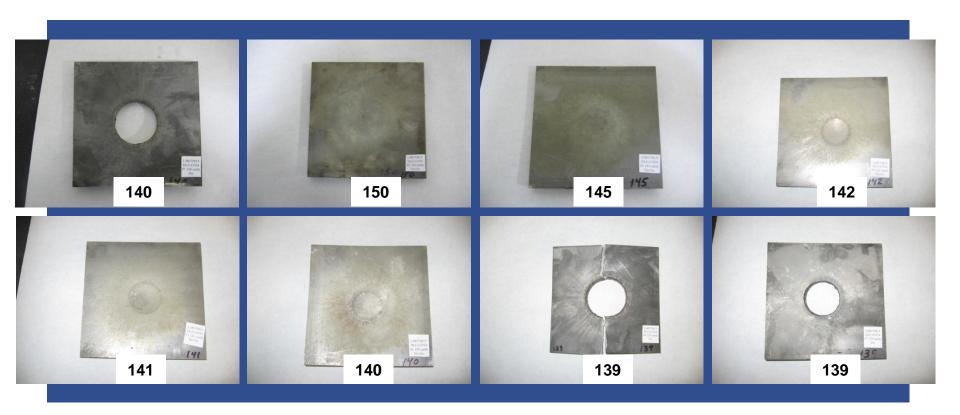


DLE-C054 LSGT Testing



Large Scale Gap Testing Performed (8 tests)

- 140 cards (compared to 201 for Comp B)
- Significant reduction in shock sensitivity compared to Comp B



DLE-C055 Formulation and Processing



A premier aerospace and defense company

Formulation

- HTPB binder system
- 88% Solids
 - Coarse RDX
 - Coarse TEX (4,10-dinitro-2,6,8,12-tetraoxa-4,10-diazatetracyclododecane)
 - Fine RDX

Processing

- Viscosity minimized by adjusting ratio of coarse and fine RDX
- Excellent processing with end-of-mix viscosities from 7-11 kp
- Material flows easily through slit or hole plate when casting
- Made in ¼ pint, pint, and 1-gallon mix sizes

Insensitive Energetic Material TEX

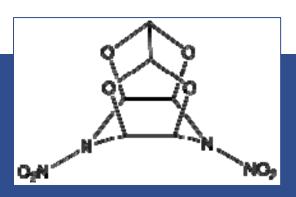


A premier aerospace and defense company

TEX

- 4,10-dinitro-2,6,8,12-tetraoxa-4,10-diazatetracyclododecane
- Cheetah thermochemical code theoretical performance a little better than NTO
- Has been manufactured in the past at ATK Launch Systems
- Not currently manufactured in large quantities in the US
- Synthesis starts with inexpensive materials has the potential to be reasonably low cost

Caged molecular structure results in high density of 1.99 g/cc

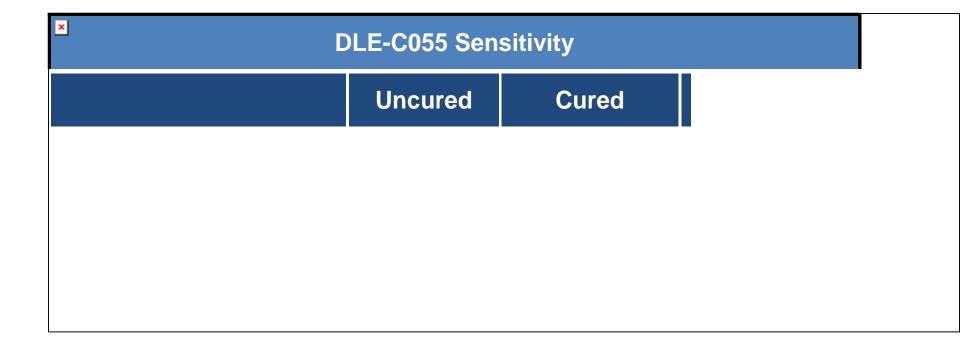


DLE-C055 Small Scale Sensitivity



A premier aerospace and defense company

Excellent sensitivity



DLE-C055 Dent/Rate Tests

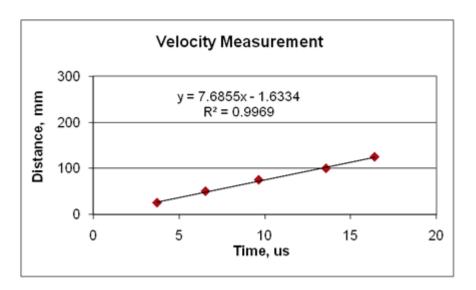


Two dent/rate tests performed

• LSGT Hardware (13.97 cm long by 3.65 cm diameter charge)

Excellent performance

Detonation velocity = 7.7 km/s (Comp B = 7.9 km/s)



Dent Depth (DLE-C055)	Dent Depth (Comp B)	Percentage of Comp B
0.419"	0.433"	97%

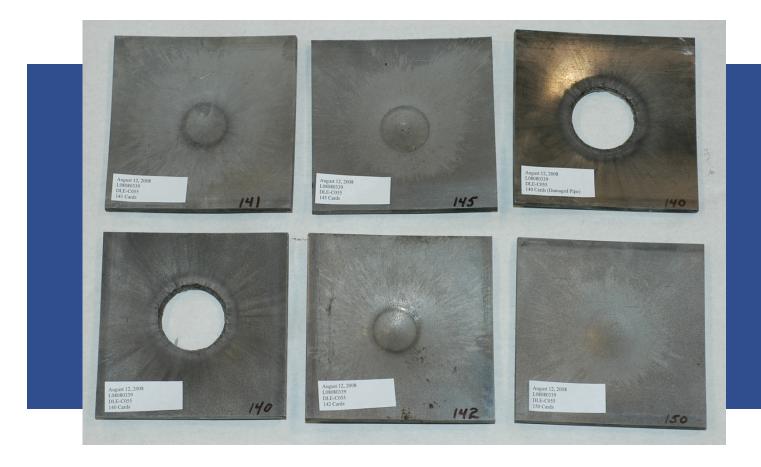


DLE-C055 LSGT Testing



Large Scale Gap Testing Performed (6 tests)

- 141 cards (compared to 201 for Comp B)
- Significant reduction in shock sensitivity compared to Comp B



Summary and Conclusions



DLE-C054 is a promising composition for Comp B replacement

- Good performance
- Excellent shock sensitivity compared to Comp B
- Good small-scale slow cookoff response
- Excellent processing characteristics
- Potentially low cost

DLE-C055 has features very similar to DLE-C054 but with improved performance

 However, a good commercial source of large quantities of TEX is not available at this time

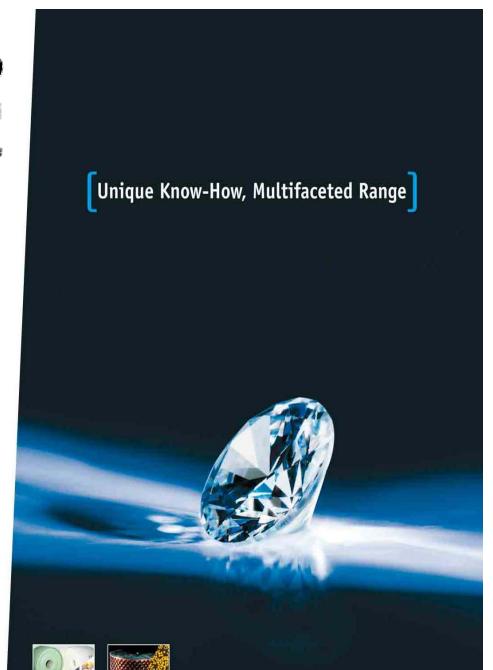


ading international partner for Explosives and Prepellants

ailored Sensitivity blosive Formulations

B. Nouguez – B. Mahé

IMEMTS, Tucson May 2009





OUTLINE



- Scope
- Method
- Desirable characteristics
- Formulation phase results
- Assessment against SCj
- Conclusions



SCOPE



Define Cast PBX formulations for IM large calibre applications (155mm)

- Meeting SD and SCj without shielding/packaging
- Using mature raw materials (RDX, NTO, Al, binder)
- Using batch or proprietary bicomponent process



Method



- Establish target characteristics
- Measure the influence of NTO/RDX ratio against specs
- Finalize 2 formulations (without and with Aluminium)
- Assess against SCj with 155mm shells



Desirable Characteristics



• LSGT \leq 100 cards (STANAG 4488 annex B)

79 kbar, end of gap pressure

• ELSGT ≤ 50 mm PMMA (STANAG 4488 annex C)

62 kbar, end of gap pressure

• $\Phi_{crit} \leq 50 \text{ mm}$



Preliminary results



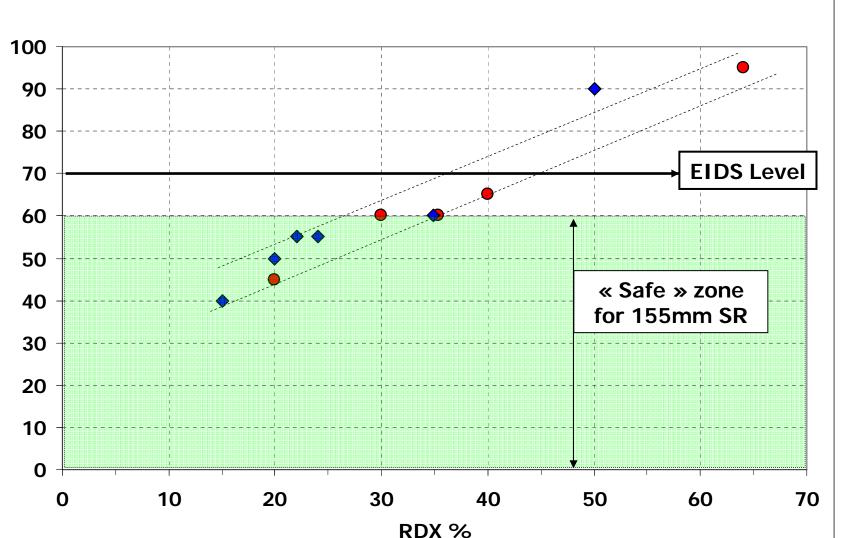
ing)	NTO (%)	I-RDX ® (%)	NTO/RDX	ISGT (cards)	ELSGT (mm PMMA)	Critical Diameter (mm)
	44	40	1.1	100	65	19 < Φ _c < 25
	49	35	1.4	90	60	$25 < \Phi_{\rm c} < 30$
	54	30	1.8	80	60	$30 < \Phi_{\rm c} < 36$
	64	20	3.2	40	45	$50 < \Phi_{c}$
	51	35	1.5	125	60	$13 < \Phi_{\rm c} < 19$
y	62	24	2.6	100	55	$25 < \Phi_{\rm c} < 30$



Preliminary results









Final Formulations



	B2267A	B2268A
ormulation		
	I-RDX ® / NTO	I-RDX ® / NTO / AI
	НТРВ	НТРВ
scosity (Pa.s)		
at casting time	100	300
6 hours after casting	250	600
ensity	1.65	1.76
echanical properties		
Max tensile stress (MPa)	0.72	0.72
Max tensile strain (%)	7.2	8.6
ardness (Shore A)	70	71
etonation velocity (m/s)		
cylinder Ø 50 mm	7570	/
computed	7680	7440
GGT (cards)	95	< 1
LSGT (mm PMMA)	55	40
nconfined Critical diameter (mm)	$30 < \Phi_{\rm c} < 36$	50 < Φ _c



Assessment against Shaped Charge Jet - 155mm shells



Test reference : STANAG 4526 ed.2

Shaped Charges: Φ 68 mm

(provided by TDA)

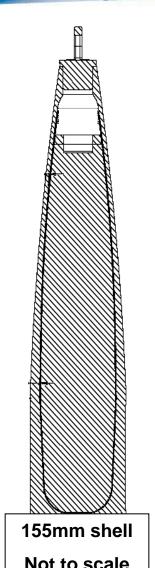
Shell bodies: 155mm

(provided by RWM)

Explosive grains: 1. B2267A

(≈ 9 Kg)

2. B2268A



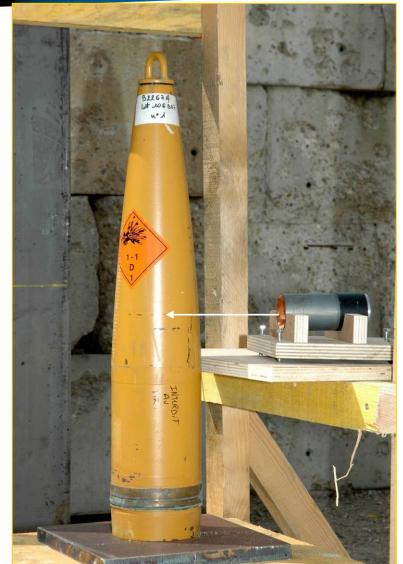


Shaped Charge Jet Tests 155mm shells





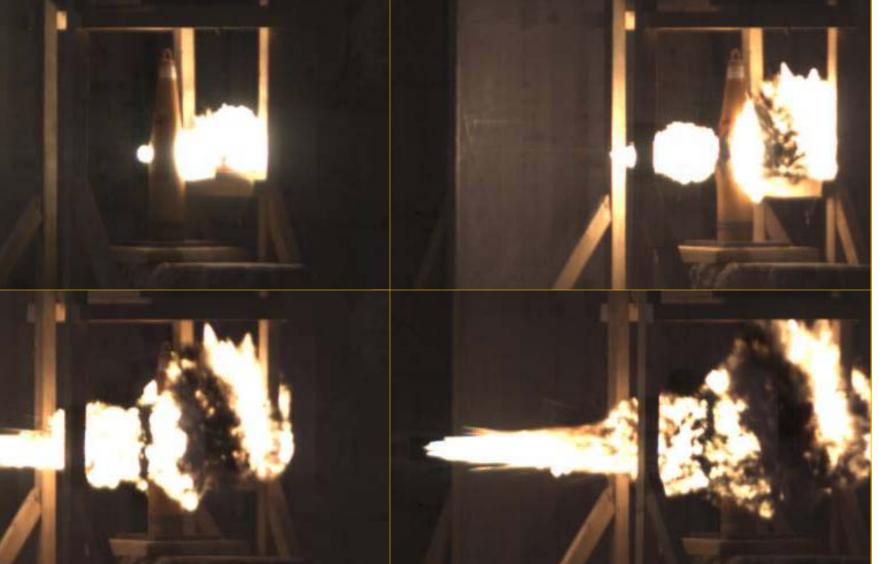






Shaped Charge Jet Test 155mm - B2267A







Shaped Charge Jet Test 155mm - B2267A

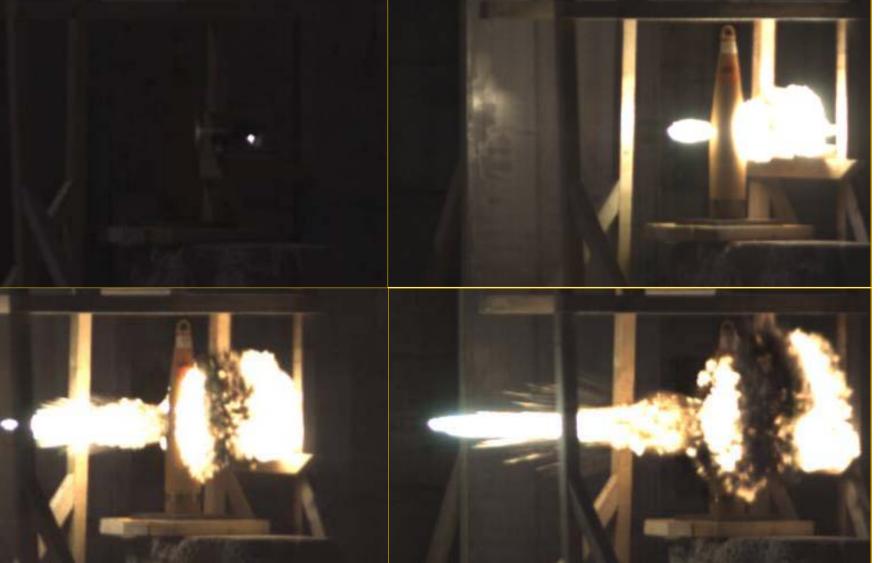






Shaped Charge Jet Test 155mm - B2268A









Conclusions



EURENCO has tailored new cast PBX formulations, NTO/RDX based, which exhibit optimized IM/Performances trade-offs for large caliber pplications.

ow level gap test results allow B2267A and B2268A to meet EIDS criteria as well as Sympathetic Reaction requirements in 155mm configuration.

32267A fully meets STANAG 4439 Shaped Charge jet requirement (Reaction Level III)

32268A largely exceeds STANAG 4439 Shaped Charge jet requirement Reaction level V, burning).

32268A is a suitable formulation to get, at no risk, fully STANAG 4439 compliant munitions ranging from 155mm shells to 500 lbs class aircraft bombs with performances equivalent to PBXN-109.





Recent Developments in Composition C-4: Towards an Alternate Binder and Reduced Sensitivity

NDIA Insensitive Munitions & Energetic Materials Technology Symposium 2009



Paul Vinh RDECOM-ARDEC, Picatinny Arsenal







Presentation Outline

- Research Extrudable Moldable Insensitive eXplosive (OSX-REMIX)
 - Background
 - **Program Objectives**
 - Technical Approach
 - Formulation and Evaluation
 - Summary
- Alternate Plastic-binder Extrudable eXplosive (OSX-APEX)
 - Background
 - **Program Objectives**
 - **Technical Approach**
 - **Formulation**
 - Modified Accelerated Aging Trial
 - Summary

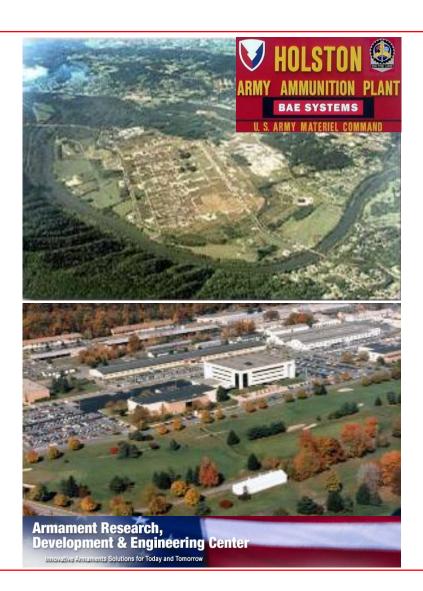






Acknowledgement

- PM-CCS
 - Mr. Felix Costa
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 - Mr. Gregory Tremarco
- BAE SYSTEMS OSI
 - Mr. Jim Haynes
 - Ms. Kelly Guntrum
 - Mr. Alberto Carrillo
 - Mr. Matt Hathaway
 - Mr. Brian Alexander







OSX-REMIX – Program Objectives

- Composition C-4 already fares well in the arena of insensitivity, due to relatively large amount of binder.
 - Passes Bullet Impact and Fragment Impact (Army) sensitivity tests at ambient temperature.
 - Fails shock stimulus Sympathetic Detonation and Shaped Charge Jet.
- BAE's task to develop an alternate extrudable formulation with similar physical and energy output characteristics, while enhancing its insensitivity.
 - Maintain current binder configuration for comparison to standard C-4.
 - Identify modifications to process or alternate input energetics.
 - Formulate and evaluate physical and energetic properties.





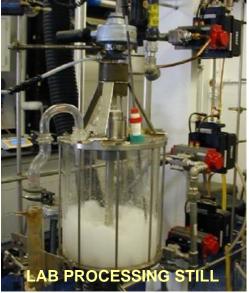






OSX-REMIX – Technical Approach

- Modification to manufacturing process.
 - Maintain aqueous slurry-coating process.
 - Premixing RDX with fluid portion of binder (DOA/Oil).
 - Reduced sensitivity in Melt Cast applications.
- Modification of traditional formulation.
 - Manipulation of Coarse: Fine.
 - Finer particle nitramine has shown decreased shock sensitivity.
 - Manipulation of nitramine energetic input.
 - FEM RDX.
 - HMX may prove lower shock sensitivity.











OSX-REMIX – Technical Approach

- New, readily available, energetic ingredient to replace some or all RDX.
 - 3-nitrotriazol-5-one (NTO) has shown promise as next-generation ingredient in IM formulations.
 - Comparable energy to RDX, decreased sensitivity.
 - Water solubility proves challenging in aqueous slurry system.
 - 1,3,5-triamino-2,4,6-trinitrobenzene (TATB) is comparable to RDX in energy output, and shows high stability to thermal, shock, and impact/friction stimulus.
 - High cost.
 - Perfectly suited for aqueous slurry-coating manufacturing process.
 - Available in two particle sizes (5μm, 40μm).

$$O_2$$
 O_2 O_2

TATB







OSX-REMIX – Modification of Current C-4 Formulation

Modification	Moldability (physical feel)	NOL LSGT (50% card gap)
None – Standard C-4 for baseline		150 – 160 cards
Premix RDX with DOA portion of binder	Identical to Standard	No improvement
Coarse : Fine 2:1	More firm, harder to mold	No improvement
Replace Fine RDX with CL5 HMX	Slightly tougher than Standard C-4	No improvement
Replace Fine RDX with 2.8um FEM RDX	Significantly less moldable	No improvement

- Samples for LSGT were prepared by mechanically pressing bulk C-4 to a density of 1.55
 1.65 g/cc. Four pellets of equivalent mass / density filled each tube.
- Insensitive candidates were tested at 135 cards (two shots).
 - 10% decrease in sensitivity deemed significant enough for further testing.







OSX-REMIX – New Energetic Components

Modification	Moldability (physical feel)	NOL LSGT (50% card gap)
None – Standard C-4 for baseline		150 – 160 cards
Replace Fine RDX with 5µm TATB	Very poor compared to Standard	No improvement
Replace Fine RDX with 40µm TATB	Comparable to Standard	142.5 cards

40µm TATB replacing the standard CL5 RDX shows some promise in reducing

shock sensitivity.

Plate Dent testing shows comparable blast performance (96% of standard C-4).

Examination of LSGT plates tells different story.











OSX-REMIX – New Energetic Components









OSX-REMIX – Summary and Conclusions

- As proof of concept, an extrudable, moldable formulation with enhanced IM properties was conceived and manufactured at laboratory scale.
 - Modification to nitramine used or coarse / fine ratio did not show significant changes to shock sensitivity.
 - 40µm TATB replaces CL5 RDX in standard Composition C-4 formulation, but provides an inferior general purpose demolition explosive.
 - High cost TATB.
 - Poor metal-cutting properties.
 - Standard aqueous slurry coating process precludes the use of more economical energetic candidates of interest.







OSX-APEX - Background

- Composition C-4 is a legacy explosive formulation with decades of use.
 - 90.5% RDX.
 - Specific ratio of coarse to fine RDX.
 - 9.5% plastic binder.
 - High molecular weight polyisobutylene (PIB).
 - Dioctyladipate (DOA).
 - Lightweight motor oil (Oil).
- Composition C-4 is mainly used for demolition purposes.
 - M112 Demolition Charge.
 - M183 Demo Kit.
 - MICLIC.
 - M18A1 Claymore Mine.











OSX-APEX - Background

- Composition C-4 is extruded to generate the M112 Block.
 - M112 blocks should be moldable / pliable.
 - Blocks have shown poor physical characteristics after long-term storage.
 - Dry, crumbly feel.
 - Onsite rework with additional plasticizer (motor oil) necessary, timeconsuming, and potentially hazardous.













OSX-APEX – Program Objectives

- Explore and formulate an extrudable demolition explosive comparable to Composition C-4.
 - Equivalent energy output and blast effect.
 - Comparable physical properties and moldability.
- Enhance long-term storage issues with an alternate binder.
 - Accelerated aging trial.
 - Intrinsic viscosity.
- Produce large-scale manufactured quantities of an acceptable material for M112 production and trials.







OSX-APEX – Technical Approach

- Current binder is 9.5% of Composition C-4.
 - 25% of binder is a high molecular weight polyisobutylene rubber.
 - 75% of binder is a combination of dioctyladipate (DOA) and lightweight motor oil.
 - Both low molecular weight liquids at ambient.
 - DOA has historic tendency to leech and exude from certain premixes.
 - Large disparity between molecular weights (viscosities) of polymer and plasticizer may have resulted in these components not complementing one another.
 - Nonuniformity of coating during manufacturing process.
 - Segregation during drying, tagging, packaging.
 - Ultimately poor aging characteristics due to exudation and leeching.
- Replace standard binder with a set of components with similar chemistry and viscosity.
 - Better match.
 - Treat binder as a "system", allowing for ease of modification for unique applications.

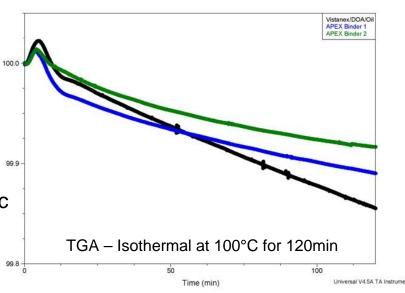






OSX-APEX – Technical Approach

- Polyisobutylene is well-suited for moldable, extrudable explosive formulation.
 - Physical properties.
 - Available in a wide range of molecular weights.
- Complementary component sought for the high molecular weight PIB.
 - Liquid PIB oligomers available in a range of viscosities.
 - Oligomeric constituents should provide increased stability to leeching and exudation.
 - Heavily utilized in cosmetic and personal care industries.
 - Comparable in price to DOA and motor oil.
- Initial investigation gave promising results.
 - Easily dropped in to current slurry coating manufacturing process.
 - Current analytical regime performs well in new system.
 - Blends of PIB polymers and oligomers show good thermal stability via Thermal Gravimetric Analysis (TGA).

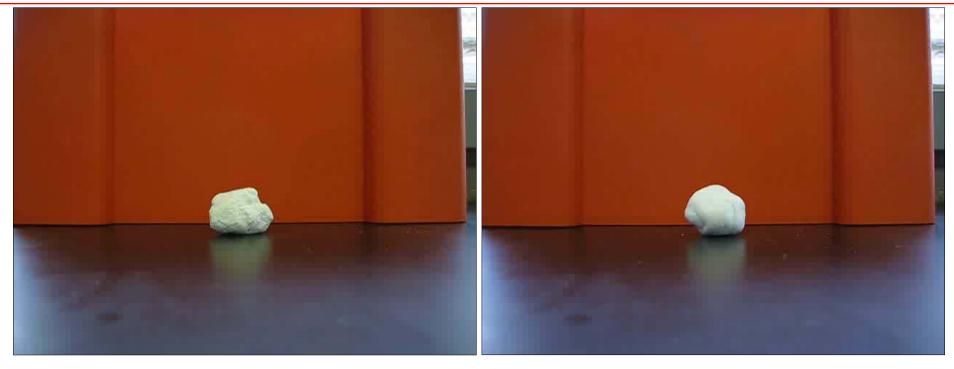








OSX-APEX – Formulation and Evaluation



- Several binder system candidates were formulated at laboratory scale for evaluation.
 - Particle size distribution of energetic input is same as standard Composition C-4.
 - APEX binder systems easily dropped in to standard slurry coating process.
 - Lab scale manufacture of standard binder C-4 performed as baseline for comparison.
- All analytical testing, as well as qualitative "look and feel" tests show that alternate binder systems are comparable to legacy Composition C-4.







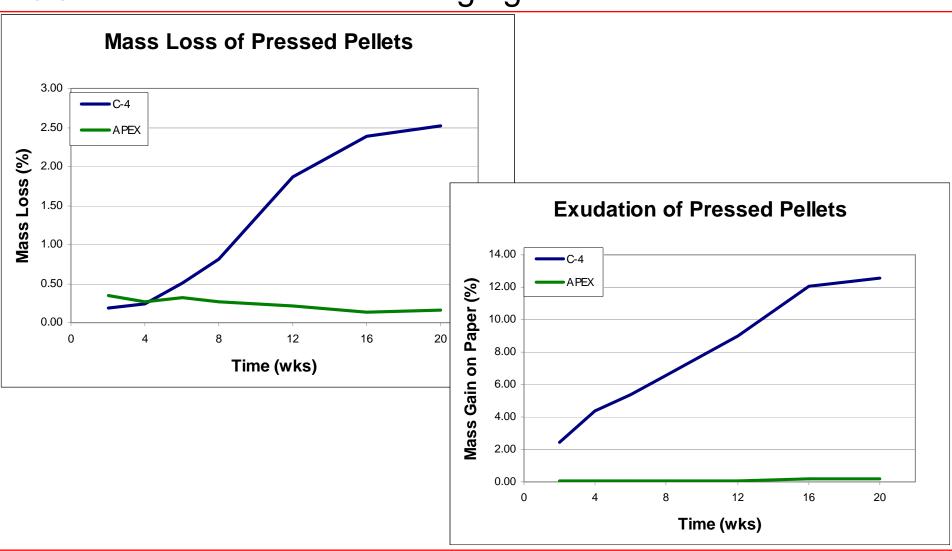
- After initial laboratory investigation and testing was completed, accelerated aging trials were initiated.
- Standard binder C-4 and OSX-APEX were prepared using identical input RDX batches and octane source (3 lb. scale for both).
- Aging performed at 75°C on bulk material and mechanically pressed pellets.
 - Composition and plasticity and "feel" of bulk material.
 - Growth, exudation, and mass loss of pressed pellets.







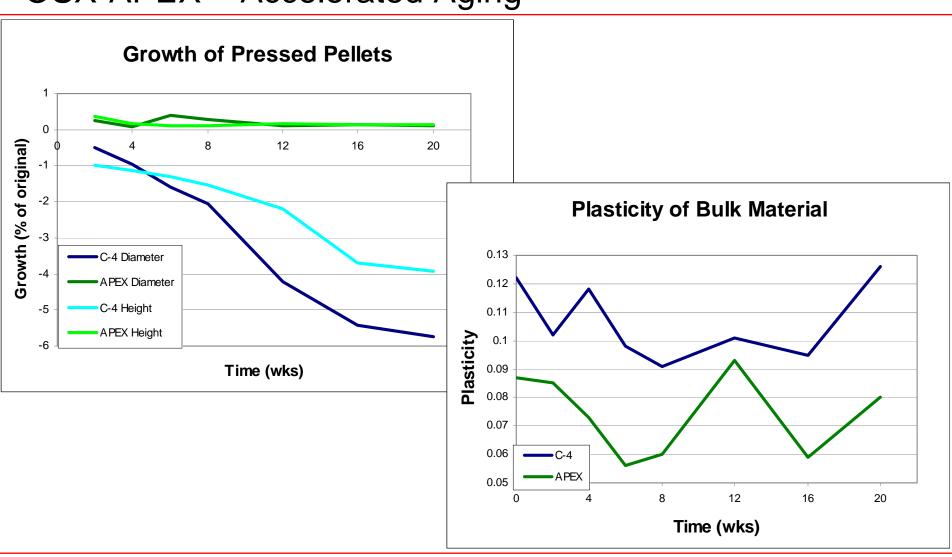








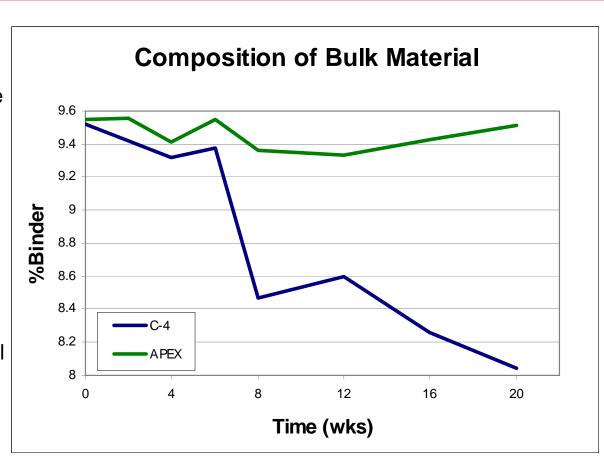








- Accelerated aging trial shows OSX-APEX fares very well in comparison to Composition C-4.
- APEX is significantly more stable to growth / shrinkage.
- APEX has virtually no exudation issues; Paper under standard Composition C-4 is literally wet with DOA / Oil plasticizer.
- APEX's mass and composition are very stable over time; C-4 loses over 15% of its binder over 20 weeks.
- Significant differences in material "feel".
 - Comp C-4 becomes grainy, soft, and crumbly over time.
 - APEX retains good physical characteristics at 20 weeks.
 - Plasticity data inconclusive, as it contradicts the "feel" test.







Conclusions and Future Endeavors

- OSX-APEX has been developed as an alternate extrudable demolition explosive.
 - Comparable physical properties as newly manufactured Composition C-4.
 - Superior physical characteristics after accelerated aging trial.
 - By developing a binder "system", individual applications may have unique formulation tailored for use.
- Future endeavors include further evaluation of physical parameters.
 - Simulation of actual production environment.
 - Lab-scale drying kettle.
 - Lab-scale conical mixer.
 - Intrinsic viscosity via capillary rheometry.
- Verify OSX-APEX sensitivity and performance properties.
- Large scale manufacture of OSX-APEX.
 - M112 Charge Demolition Block configuration.







Questions?







Experimental Deviations from Conventional Critical Temperature Models for Non-ideal Explosive Formulations

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BAE SYSTEMS

2009 IMEMTS, Tucson, AZ 11-15 May 2009



Thermal Hazards – Why is it important?



- Prolonged exposure of energetic materials to elevated temperature
 - □ Produce some level of decomposition
 - Decomposition generates heat
 - Heat dissipates to surroundings
- Self-heating
 - Rate of heat generation exceeds losses to the environment
 - Non-catastrophic
 - √ Simple non-violent decomposition
 - √ Reaction may be stopped if heat source removed
 - ✓ Over time may escalate into catastrophic reaction
 - Catastrophic
 - ✓ Thermal runaway or "point of no return"
 - ✓ May result in deflagration, explosion or detonation



Critical Temperature



- Critical temperature, T_c
 - Defined the lowest constant surface temperature at which a given material of a specific shape and size will catastrophically self-heat
 - Utilized to assess the hazards associated with processing and loading of melt cast explosives
 - Parameter scales with charge size
 - ✓ Mass
 - ✓ Diameter
 - Other relationships for critical temperature
 - 1. Decreases as size increases
 - 2. Decreases as Surface/Volume decreases
 - 3. Determined by most rapid heat-producing reaction
 - 4. Can *usually* be predicted

RDECOM Potential Problem



Novel Explosive Formulations

- Developed to meet Insensitive Munition (IM) requirements
- ➤ Non-ideal explosives
 - ■Non-conventional ingredients (nitrate salts, NTO, DNAN)
 - □ Larger critical diameters
- Responses to thermal stimuli
 - ■Often very mild
 - ■Vary from critical temperature models (Observed with PAX-21)

What is "catastrophic"

- ➤ Catastrophe:
 - an extremely large-scale disaster (wikipedia.com)
 - □ a sudden and widespread disaster (dictionary.com)
 - □ a sudden violent change (American Heritage dictionary)
- Can the mild "events" from some non-ideal explosives be described as "catastrophic?"



Objective



- Investigate the applicability of conventional thermal models and standard tests utilized for explosive qualification
- Demonstration for non-ideal explosives
 - ☐ Evaluate Non-ideal Insensitive Explosive Formulation (NIE)
 - ✓ Melting point of 94.5°C
 - ✓ Likely be processed at 105 to 110°C
 - Critical temperature
 - √ F-K and Semenov Models are often too conservative
 - √ Conventional scaling factor does not apply
 - Processing of NIE formulation is
 - √ Safe to process and handle on large production scales
 - ✓ Despite the hazards incorrectly predicted using the traditional conservative models



Technical Approach



- Conduct experiments at multiple scales
 - Obtain required parameters and variables
 - Conventional prediciton models
 - Milligram-scale (Henkin)
 - ☐ Gram-scale (thermal screening unit and small-scale cookoffs)
 - ☐ Kilogram-scale (1-L Cookoff)
 - Multikilogram-scale (12-Liter Cookoff)
- Combine and compare results
- Make assessment



Predictive Models



- Frank-Kamenetsky (F-K) Model
 - **□**Assumes conductive heat transfer
 - **☐** Worst-case predictive model under the limitations of pure conduction
 - ■Heat flow from reacting mass to establish temperature gradient
 - ☐ In essence, this scenario is the result of a viscous melt with failed stirring

$$T_{m} = \frac{E}{R \ln \frac{A^{2} \rho QZE}{T_{m}^{2} \lambda \delta R}}$$

- >Semenov Model
 - **□**Assumes perfect stirring
 - ■Convective heat flow
 - ■Uniform temperature in the reacting explosive
 - ☐ Heat lost to surroundings by Newtonian cooling with thermal gradient at vessel boundary

$$E/T_m = R \ln \left[\frac{V \rho Q Z E}{S \alpha R T_m^2} \right]$$

- >R is the gas constant
- Q is the heat of decomposition
- $\triangleright \rho$ is the density
- > E is the activation energy
- >Z is the frequency factor
- $\triangleright \lambda$ is the thermal conductivity
- >A is the radius of the sphere, cylinder, or slab
- $\triangleright \delta$ is the shape factor
 - **□**0.88 for an infinite slab,
 - □2.00 for a squat cylinder
 - **□**3.32 for a sphere
- V is volume of the charge
- > S is the surface area of the charge
- $\triangleright \alpha$ is the heat flow coefficient at the boundary
 - ☐Glass: 0.0105-0.0135 cal/(cm²-s-°C)
 - □Aluminum: 0.0085 cal/(cm²-s-°C)
 - **☐**Steel: 0.0022 cal/(cm²-s-°C)

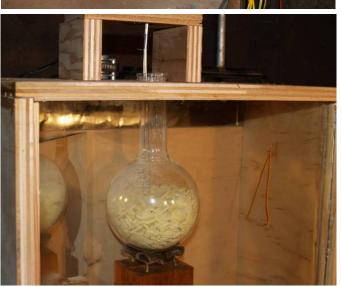


1-L Slow Cookoff Test



- ➤ Dual Purpose
 - ■Validate accuracy of self-heating predictions for larger geometries
 - ■Provides measure of reaction severity
- ▶ Preparation
 - ■1-L Pyrex round-bottom flask containing sample and thermocouple bundle
 - ■Disposable plywood oven
 - √ Resistive heater and circulating fan
 - √Tempered oven glass window for video observation
- >Test
 - ■Sample preconditioned at ~10°C > melt point
 - ☐ Heat oven at 3.3°C/hr
 - ■Thermocouple data recorded
 - □ Procedure continues until decomposition, explosion, or cracking of the flask



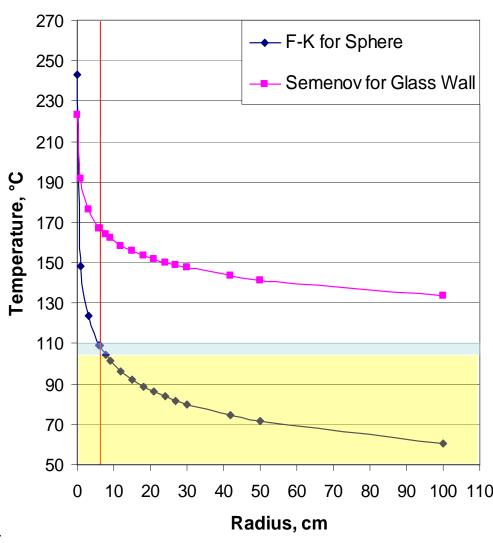




Predictions for 1-L Cookoff Scenario



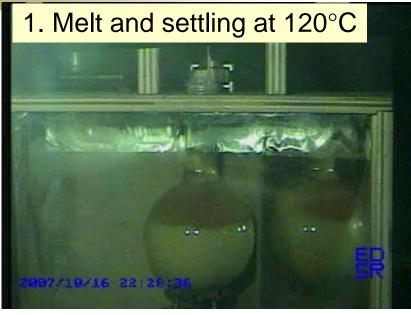
- ➤ Henkin time-to-explosion
 - □Sealed, confined sample
 - □T_c of 220°C
- >F-K
 - □For 1-L (r=6.1cm), predicts 108°C
 - □Extrapolates to T_c below melt point of formulation at large diameters
- **≻**Semenov
 - □ For 1-L, predicts 166°C
 - □Extrapolates to t_c of 134 at large diameters
- Large scale production meets 30°C safety margin *if* NIE follows Semenov closely
- ► F-K predicts T_c well below melt point!





Video Stills from 1-L Cookoff









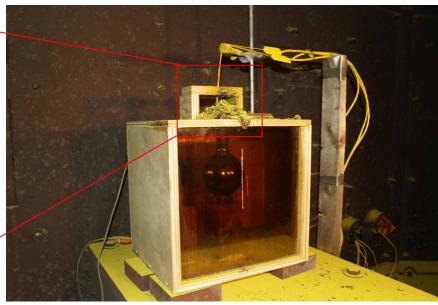




Post-test Analysis for 1-L Cookoff







- Exudate on top of oven around flask opening
- Oven intact
- Flask discolored, but undamaged
- Fine yellow coating on all horizontal surfaces
 - DNAN
 - Confirmed by DSC

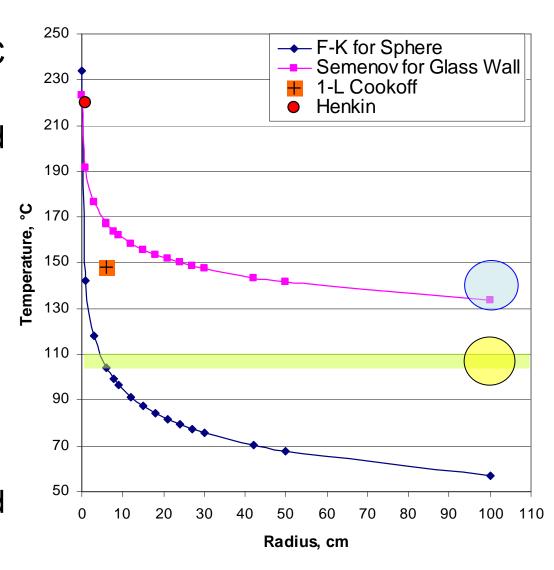




Concerns over Predictive Models



- ➤ Processing at 100-105°C
- ➤ If a curve is drawn based upon deviation from F-K and Semenov
 - ■Yellow circle
 - □T_c between 95 and 115°C
- Preferred margin
 - ■Blue Circle
 - □T_c in range of 130-150°C
- Further Testing Required

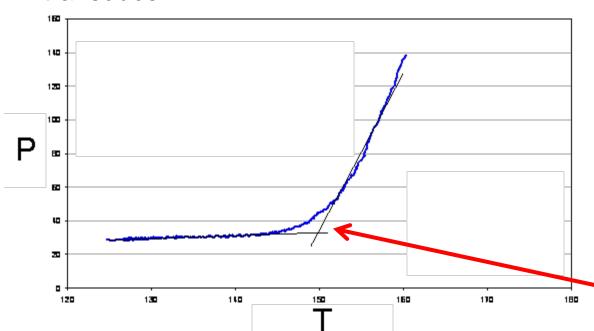




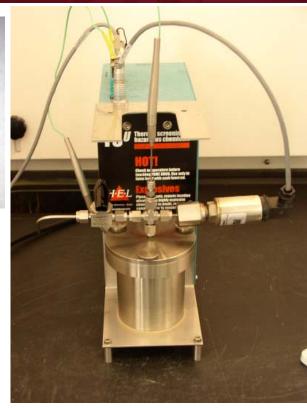
Thermal Screening Unit



- Computer controlled temperature ramp (3.3°C/hr)
- Records several parameters (temperature pressure, time) during experiment
- Uses Hastelloy Bombs (ARC type) with Type K thermocouples, pressure transducer







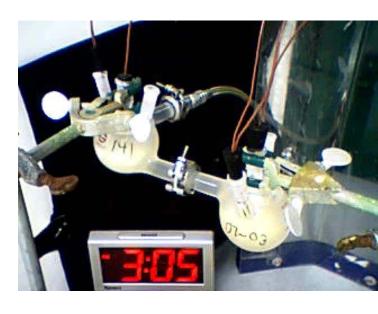
- ➤ Pressure spike and small exotherm at 150°C
- ►Inflection point at 150°C



Reduced Scale Cookoff Experiments



- Test Setup
 - ☐ Silicone oil bath (Recirculation)
 - Three Neck Jacketed Round Bottom Flask
 - Thermocouple Data Recorder (K Type)
 - 2 Thermocouples per sample (Center, Side)
 - 2 Samples run simultaneously per experiment
- Test Method
 - Limitation: Non programmable bath
 - Heated at 120°C and held for 2 hours
 - Ramped in increments of 10°C and held for 1 hr
 - Cool down was not initialized until sample returned to bath temperature



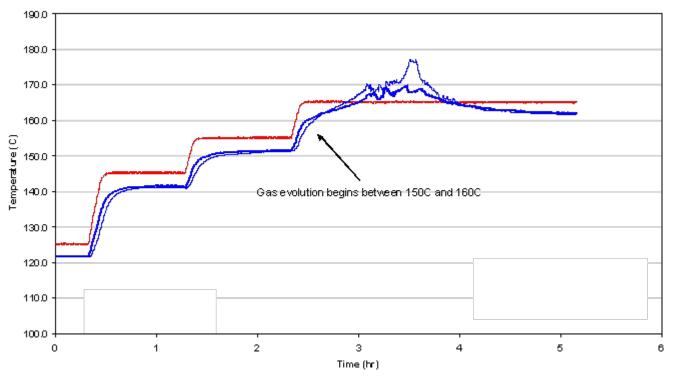
- ➤BAE used 3 varied mass/volume ratios: 15g/50ml, 30g/100ml, 30g/50ml
- ➤ ARDEC conducted similar test using 20g in 25ml flask, but at ramp of 3°C/hr



Reduced Scale Cookoff Test Data



- BAE Small Scale Cook Off Tests
 - ☐ Thermal event observed between 150 and 160°C (at all 3 scales)
 - Very mild exotherm "event"; gentle rising and cooling back into thermal equilibrium with the bath temperature



ARDEC tests observed discoloration at 140°C and self-heating at 145°C using a 3°C /hr ramp rate

Cookoff tests

- ■Multiple scales (1-L and less)
- ■Similar self-heating temperature 145-155°C
- ■Mild Response
- Conduct scale up testing in large vessel
- ■What about larger scales?

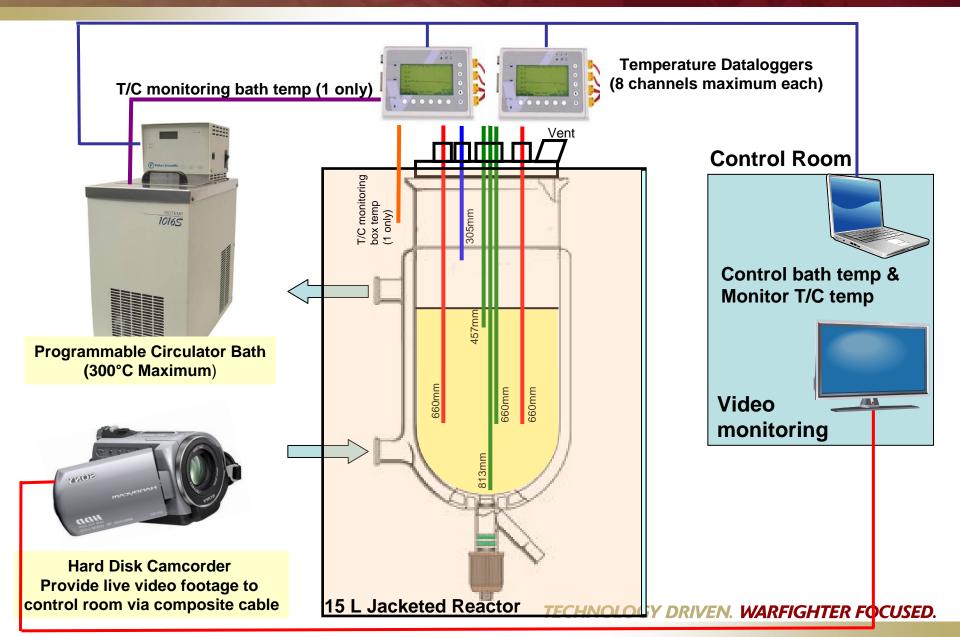
▶12-Liter cookoff test

- ■Conduct in 15-L jacketed reactor
- ■Heat with silicon oil at rate of 3.3°C/hr
- ■Performed by BAE at Holston with Army consultation
- ☐ Further demonstrate
 - √ Reaction is independent of size
 - √F-K or Semenov models predictions are too conservative
- □Geometry more comparable to production melt kettles than 1-L spherical flask



12L Cookoff Configuration

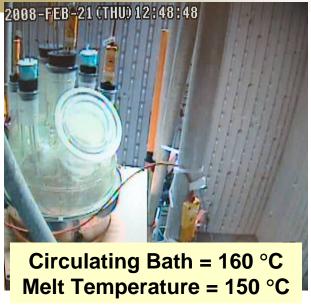


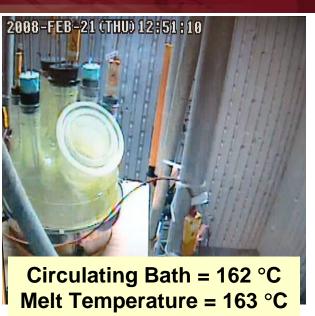




RDECOM Video Stills from 12-L Cookoff Test









T _{melt} (°C)	Observation
135	Bubbling, discoloration, and convection
140	Onset of self-heating, vigorous mixing
150	Smoke, expulsion of material Sample heating at 3x the ramp of the circulating bath
>150	Heating continued; Majority of explosive expelled T _{melt} increased to greater than 300°C



RDECOM 12-L Cookoff Post-test Analysis

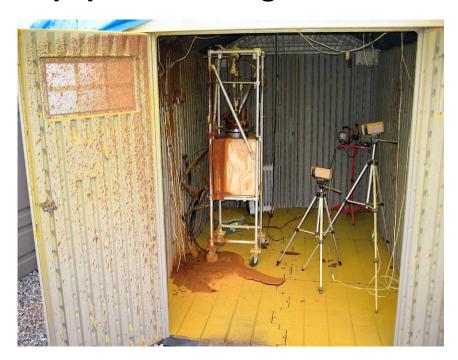




Reactor

- Undamaged
- ■Coated in ejected material
- ➤ Thermocouples still functional

- Coating of fine yellow powder
- Considerable ejected material and splatter
- No evidence of burning or equipment damage





Comparison of 1-L and 12-L Cookoff Tests on NIE



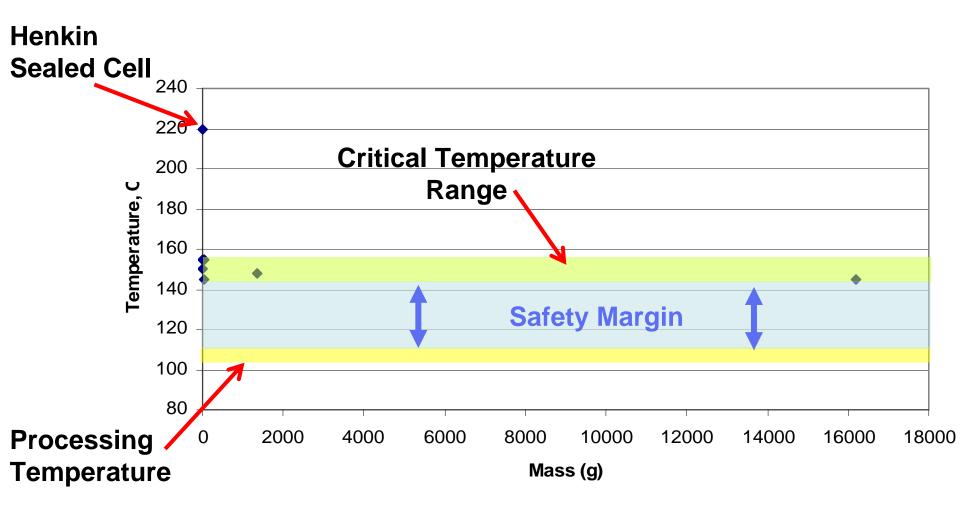
Set-up/Observation	1-L Test	12-L Test	
Excess volume/head-space	Minimal	>25%	
Venting	1 small flask neck	1 large, several small ports	
Heating	Air	Silicone oil	
Mixing/Convection	None	Significant	
Ejection	Slow exudation	Rapid expulsion	
Source of Self-heating	From center	Towards top	
Temperature of self-heating	148 °C	145 °C	
Violence of Event	None	None	
Post-test	Fine yellow powder coating	Fine yellow powder coating	



Critical Temperature vs Mass

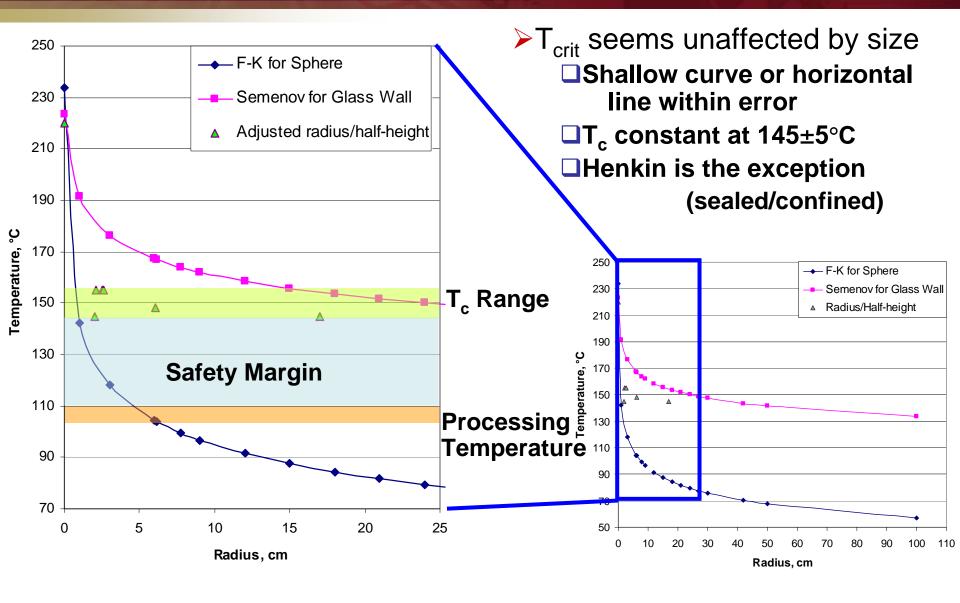


Test results from 15 to 16,200 grams (36-lb) indicate no scaling effect



RDECOM Critical Temperature vs Radius







Conclusions and Recommendations



- Non-ideal formulations
 - ☐ F-K and Semenov models are often too conservative
 - ☐ Use of sealed, confined Henkin test questionable for predictive models
 - May not follow traditional scaling rules for critical temperature
 - May lack "catastrophic" event
- Formulation NIE
 - Despite the incorrectly predicted hazards, NIE is safe to process and handle on large production scales
 - Safety margin of 35°C realized
 - Recommend processing at lower end of range suggested
- For formulation development, conduct predictive calculations
 - **☐** Best tool currently available
 - ☐ If models suggest safe processing, it is definitely safe
 - ☐ If models predict "unsafe" operations, it may be worthwhile to investigate further





Questions?



References



- 1. MIL-STD-1751A. Safety and Performance Tests for the Qualification of Explosives (High Explosives, Propellants, and Pyrotechnics) December 2001.
- 2. McKenney, Robert L. Jr, and Krawietz, Thomas R., One-Liter Test: A Mid-Scale Safety Characterization Test for Melt-Castable Explosives, AFRL-MN-EG-TR-1999-7049, July 1999.
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- 6. Frank-Kamenetsky, D. A., "Calculation of Thermal Explosion Limits," *Acta Phisicochimica U.R.S.S.*, Vol. X, pp. 365-369, 1939.
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- 8. Zinn, J. and Mader, C. L., "Thermal Initiation of Explosives," *Journal of Applied Physics*, Vol. 31, No. 2, pp. 323-328 (1960).
- 9. Semenov, N. N., Chemical Kinetics and Chain Reactions, London: Oxford University Press, 1935.
- 10. Gibbs, Terry R. and Popolato, Alphonse, editors, LASL Explosive Properties Data, University of California Press, Berkeley, 1980.
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Insensitive Munitions: Pyrotechnics Substitution for Explosives at Lake City or How ATK has paid its PWRFEE

NDIA IM/IE Technical Symposium Tucson, AZ 11 – 14 May 2009

Randall Busky;
Chemical Engineer,
ATK Small Arms Systems
ATK Lake City
Approved for Public Release, United States Department of Defense

Ref. 09 - S - 1332 08 April 2009



Lower Cost Solutions for 21st Century IM/EM Requirements ATK



An advanced weapon and space systems company

So why is a Small Caliber Ammunition person here?

- Small Caliber Ammunition are defined as insensitive munitions.
- 2. Small Caliber Ammunition is a commodity.
- 3. To be cost effective, small caliber ammunition must be
 - 1. very powerful or
 - 2. very efficient
 - a. Most IM/EM solutions are powerful and costly, see statement 2
 - b. Cost Effective Improvements therefore must be made in efficiency

ATK has followed a simple engineering design concept in substituting pyrotechnics for explosive in their designs of P₄rimer[™] and KICM[®]. The concept is

"Pay the PWRFEE"

For IM/EM, consider the alternative work paths



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Most legacy designs are very powerful and very inefficient. Insensitive munitions should consider alternate paths that incorporate insensitive energetic materials that have more efficient energy usage to perform the desired work.

The PWRFEE Defined



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Power evaluation

Work evaluation

Requirements review

Force Evaluation

Energy Assessment

Efficiency Assessment

Pyrotechnic Mixtures have been ignored



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Whereas, a primary initiating explosive is suitable for ignition of small arms propellant, it does not appear to be necessary.

The percussion cap formulations from the 1910 – 50's have more in common with chemical ignition mixtures than primary initiating explosives. Ignition mixtures appeared to have been under-explored as an alternative methodology in the search for an "environmentally friendly primer". A US patent search reveals several ignition mixtures from the 1900 – 1960s assigned for use in percussion caps. This review suggests red phosphorus as a promising candidate.

RP was considered as an alternative

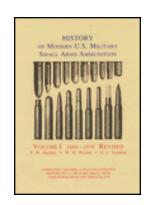


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History of Modern U.S. Military Small Arms Ammunition by Hackley, Woodin & Scranton, 1978

"Through the 1920s, the U.S. experimented with different primers in an attempt to get away from the corrosive compounds of the time. Some of these tests were identified by special headstamps.

Additional tests on primers occurred in the 1930s and again after WWII. Some were plated with tin, nickel or zinc but that alone does not automatically mean a primer is an experimental. In the late 1940s, the U.S. used zinc plating to protect primer cups on the then new **P4** primer. "

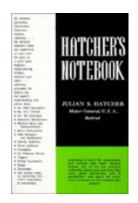


"Hatcher's Handbook" by Maj. Gen. Julian Hatcher, 1956;

"Meanwhile Frankford Arsenal's search for a perfect non-corrosive primer for other service ammunition had been progressing, and they came up with a non-corrosive primer mixture consisting of barium nitrate and red phosphorous, and started its manufacture.

..

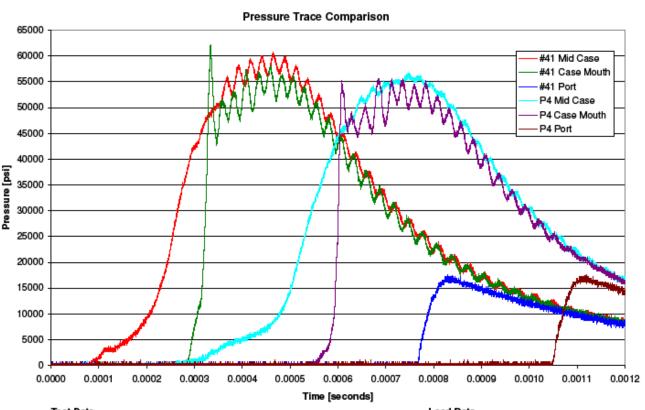
This primer mixture was used for a time (about 1949) with success; but it was finally decided to adopt a lead styphnate primer mixture for all service small arms primers, and such a non-corrosive small arms primer based on lead styphnate was standardized be Ordnance Committee action in August 1949."



Power Assessment for P₄rimerTM



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Test Data

Date: 02/21/08

Barrel: VPSAWS-444, modified for MCP testing

Samples: #41 Primer RunOrder 1 Shot 5 vs. P4 Primer RunOrder 2 Shot 15

Filter: 180 kHz

Action Time: #41 = 870 micro sec, P4 = 1170 micro sec

Load Data

Bullet: M855, BAM production

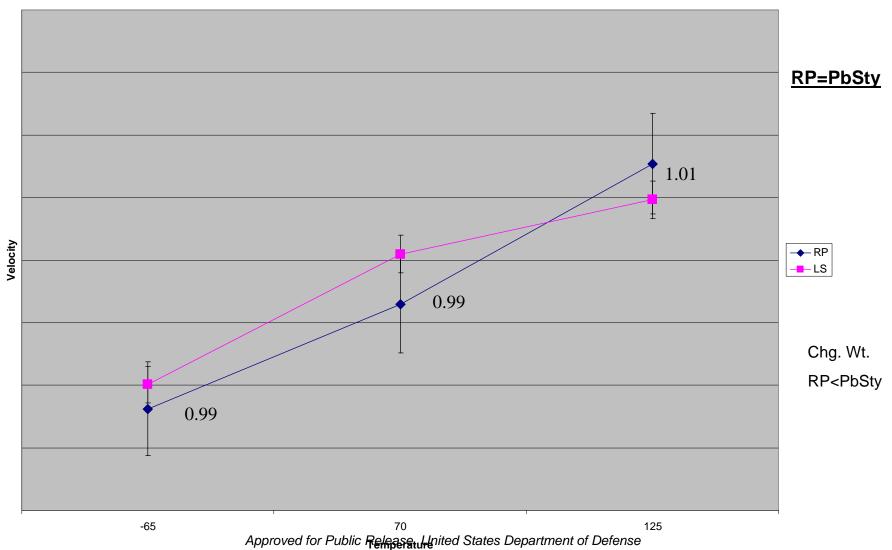
Propellant: WC844 Lot 81560 26.50 gr.

Velocity: 3000 fps



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Temperature vs Velocity



Requirements Review for P₄rimerTM



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All data at 70 F unless noted	Frankford Arsenal's P4 Primer Formula FA 675 (1947)	Frankford Arsenal's .30-06 Primer Formulation Western (WN) 768 (1947)	Frankford Arsenal's .30-06 Primer Formula FA 70 (1947)	ATK's Federal® 195 P₄rimer™ Composition (2004)	US Army's #41 Primer P₄rimer™ Composition (2007)	US Army's #41 Primer FA 956 (2007)
Peak Pressure	-3.0%	0	0	-4.6%	-11.2%	0
TTPP	NA	NA	NA	+7.7%	0	0
PP at +120 degrees F	-2.0%	0	0	-4.4%	0	0
PP at -65 degrees F	-4.1%	+2.0%	0	-5.2%	0	0
Velocity	-1.3%	-2.3%	0	0	0	0
Velocity Std Dev	+2.0%	+1.9%	0	+2.1%	+2.0%	0
Action Time	0	-14%	0	+10%	+27%	0
Misfires per 1000	9.7	0	0	2.3	6.5	0

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Design vs. Specification as Requirements



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Don't confuse a descriptive specification with a design requirement.

Design Rule:

"Primer Must Ignite Propellant at all temperatures"
Thermodynamic requirement

Specification Rule:

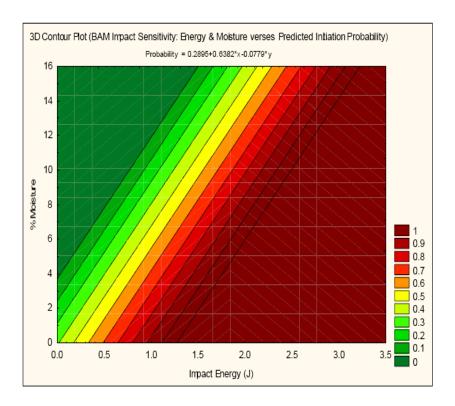
"Zero misfires in XXX cartridges at cold temperature" Systems requirement describing function

P₄rimerTM has the same mechanical activation energy

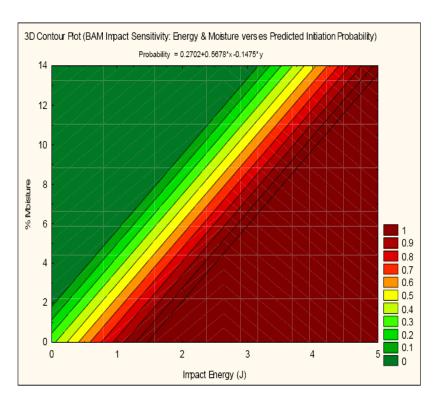


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BAM Impact Ignition Probability for ATK P4



BAM Impact Ignition Probability for FA 956



as functions of Energy and Moisture

Impact ignition for P₄rimer™ and FA 956 are very similar.

P₄rimerTM is a cost effective substitute



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- Cost effective
 - 33% reduction in cost Legacy Formulations
 - 40% reduction for mass in primer

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- P₄rimerTM is a Non-corrosive, "Green", Nutrient Mineral Containing, Non-Toxic, Heavy Metal Free Ignition Mix
 - Non-corrosive as tested in "Frankford Arsenal's Report Number R-265 Caliber .30 Red Phosphorus Primers Research Item Number 204.0"
 - Meets requirements for Section 5 of the US Federal Trade Commission Act; Federal Trade Commission Guides for the Use of Environmental Marketing Claims, Part 260 and US Environmental Protection Agency in publication EPA 260-B-01-001 as applied to the terms; "green", "heavy metal free" and "non-toxic"
 - Mix Chemicals and Combustion Products are chemical precursors for agricultural fertilizer as nutrient minerals
 - Uses Biologically tolerant and recyclable chemicals

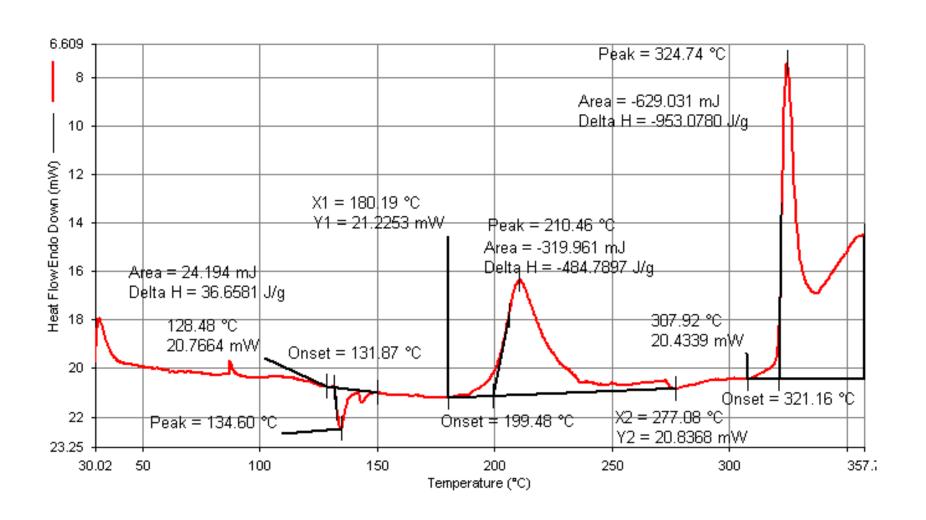
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TABLE 2 CHEETAH© Detonation Comparison Summary

Characteristic	FA 956	P4rimer [™]
Shock Velocity (m/s)	6601	3693
Particle Velocity (m/s)	1411	673
Mechanical Energy of Detonation (kJ/cc)	9.142	4.097
Thermal Energy of Detonation (kJ/cc)	0.976	4.731
Total Energy of Detonation (kJ/cc)	10.118	8.828
Heat of Combustion (cal/g)	1092	1560

$$V_{FA~956} \sim = 2V_{P4}$$
 therefore

$$F_{FA\ 956} = 4F_{P4}$$

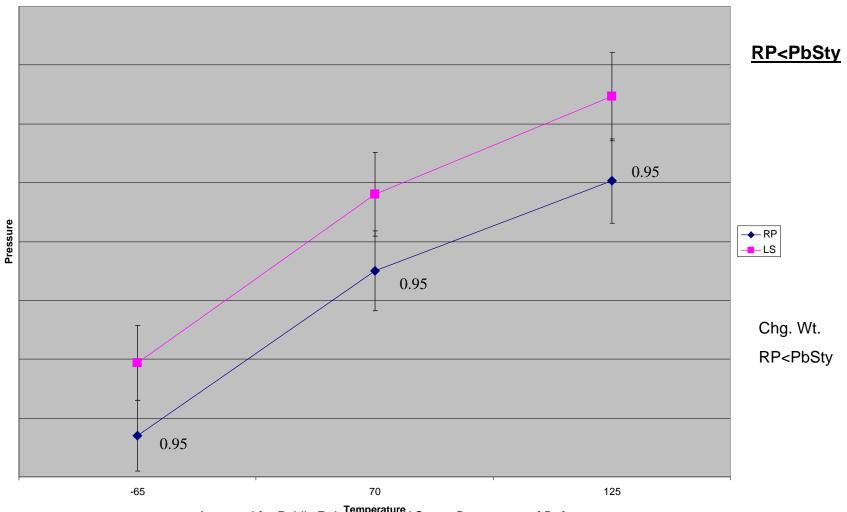


Efficiency Assessment for P₄rimerTM



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Temperature Pressure for M855

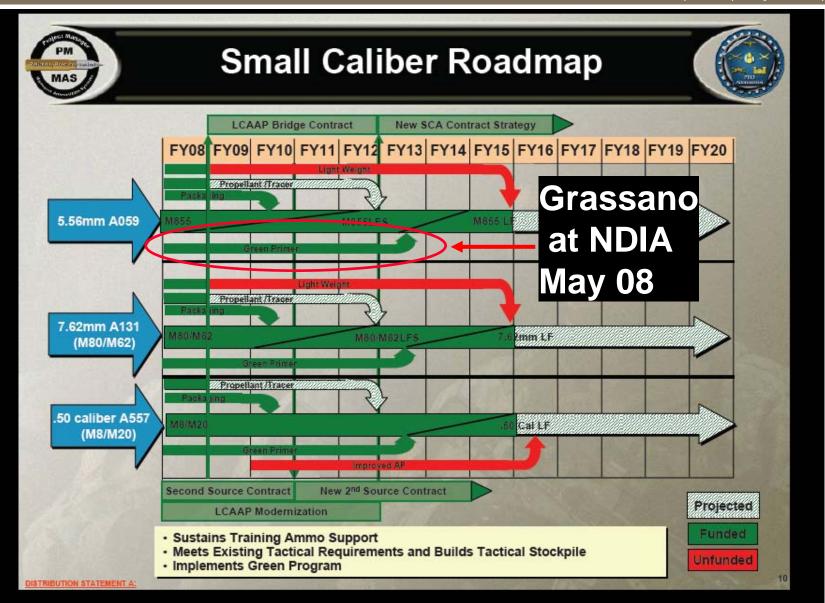


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US Army has committed to a new primer



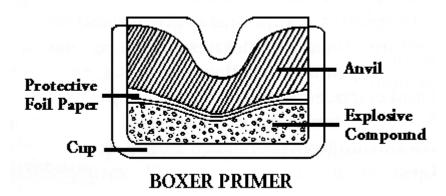
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Another Application for POWERFEE



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 P_4 rimerTM

Kinetic Initiated Core Munitions KICM®





Power evaluation

Work evaluation

Requirements review

Force Evaluation

Energy Assessment

Efficiency Assessment

Incendiary Mixtures have been ignored



An advanced weapon and space systems company

Whereas, a secondary explosives are suitable for use as a incendiary, it does not appear to be necessary.

The incendiary formulations from the 1910 – 50's have more in common with chemical ignition mixtures than secondary explosives. Ignition mixtures appeared to have been under-explored as an alternative methodology in the search for an "environmentally friendly incendiary mixture". This review suggests reactive material as a promising candidates.

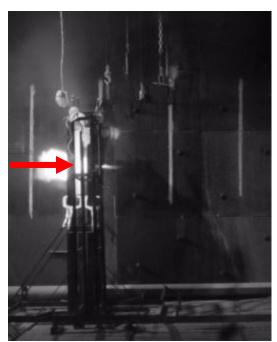
Power Assessment for Legacy and KICM Cartridges

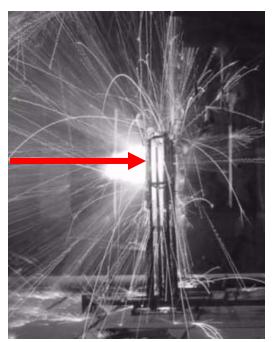


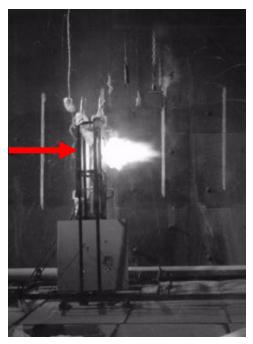
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This product's innovation: KICM differentiates from the legacy cartridges by releasing chemical energy after initial penetration.

→ Direction of Fire







M8
Armor Piecing Incendiary

MK211
High Explosive Incendiary

KICM®
Semi-Armor Piecing High Explosive Incendiary

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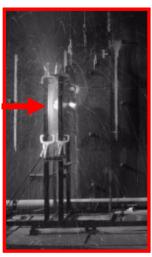
Changes In KICM's™ Modular Design Produces **Different Explosive Effects**

Direction of Fire

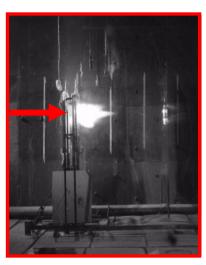




Point Ignition



Secondary **Impact Ignition**



Deep Impact Ignition

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Requirements Assessment for KICM



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Direction of Fire



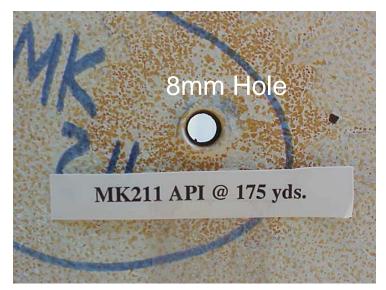


KICM® Mk 211

KICM® ignites deep in the Multi Plate Test Array. Legacy Projectile detonates earlier in this array.

Force Assessment for KICM

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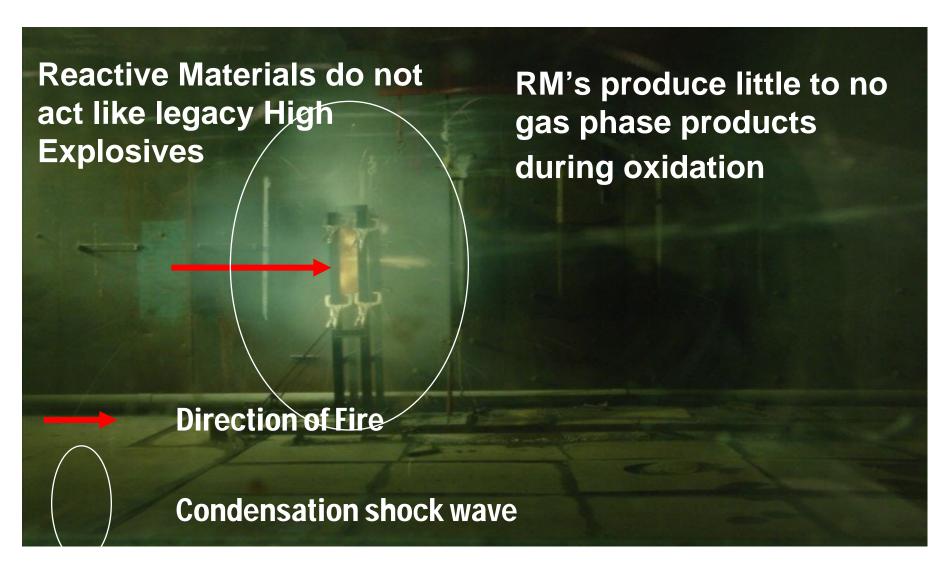
Penetrated Primary Plate Ignition on Second Impact Plate

<u>Terminal Ballistics Improvement</u>: Ignition inside or exit of the target has a greater chance of secondary explosions to immobilize target.

Efficiency Assessment for KICM



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The US Navy selected the legacy round



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Legacy producer dropped price of projectile

US Navy's Qualification Costs became prohibitive.

C'est la vie, It's still a commodity market

For IM/EM, consider the alternative work paths



An advanced weapon and space systems company

Most legacy designs are very powerful and very inefficient. Insensitive munitions should consider alternate paths that incorporate insensitive energetic materials that have more efficient energy usage to perform the desired work.

ATK Lake City has been successful with the **PWRFEE** concept in developing lower cost alternatives like P4rimerTM and KICM® while enhancing the IM/EM characteristics of small caliber ammunition.







THERMAL ANALYSIS OF IMX-101 THROUGH LARGE SCALE SLOW COOK OFF TESTING

NDIA Insensitive Munitions & Energetic Materials Technology Symposium 2009



Alberto Carrillo*

BAE SYSTEMS OSI, Holston Army Ammunition Plant







Why Investigate Thermal Hazards?

- Exposure to elevated temperatures over time can lead to
 - Decomposition
 - Self-heating
 - Point at which heat generated exceeds heat lost to surroundings
 - Can lead to both catastrophic and non-catastrophic events
- An assessment of an energetic material's thermal hazards are necessary to determine safety margins for processing and loading
 - Critical Temperature (T_c) is utilized most often to asses the thermal hazards associated with processing and loading of melt cast energetic materials
 - Defined as the lowest constant temperature at which a given material of a specific shape and size will catastrophically self heat
 - Affected by mass and shape
 - Several mathematical models for T_c determination exist







Required Testing for Qualification

- Mandatory Thermal Evaluations for Qualifications of Explosive
 - Critical Temperature Calculation
 - Test Method 1074 of MIL-STD-1751A
 - Mathematical determination utilizing Differential Scanning Calorimetry (DSC)
 - 1 Liter Cook Off Test
 - Test Method 1075 of MIL-STD1751A
 - Slow heating (3.3°C/hr) of material to determine self-heating temperature
 - Evaluation of decomposition reaction
 - Results from both tests and thermal models used to predict T_c at large scale
 - Frank-Kamenetskii (F-K) model for conductive heat transfer with no agitation

$$T_{c} = \left(\frac{E_{a}}{R} \ln \left(\frac{d^{2} \rho Q Z E_{a}}{T_{c}^{2} \lambda \delta R}\right)\right)$$

Semenov model for convective heat transfer with agitation

$$T_c = \left(\frac{E_a}{R} \ln \left(\frac{T_c^2 S \alpha R}{V \rho Q Z E_a}\right)\right)$$







Background

- IMX–101 is a non-traditional IM Melt Cast Formulation
 - Manufactured at HSAAP utilizing existing infrastructure
 - Melting point of 96°C to 98°C by DSC
 - Processed at greater than 100°C
- 1 Liter Cook Off
 - Experienced <u>non-catastrophic</u> event between 142°C and 149°C
 - Predictions for T_c using F-K and Semenov models are extremely conservative
 - F-K extrapolates to value below melting point at large diameters
 - Semenov extrapolates to a T_c of 130°C at large diameters
 - Result (with scaling effect considered), suggested IMX-101 was not safe to handle in large scale production as its T_c was considered too low
- Holston Small Scale Cook Off Testing
 - Various amounts (small scale) tested at fast and slow heating rates also experienced mild thermal event between 145°C and 155°C
 - Similar finding to the 1 Liter Cook Off Test, suggests T_c prediction is <u>not</u> affected by <u>reduction</u> in material mass







Background (cont)

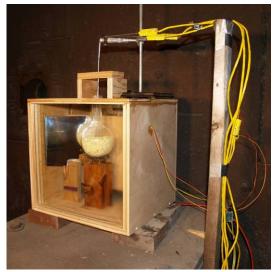
Holston Small Scale Cook Off Test





1 Liter Cook Off Test





Photos of 1 Liter Cook Off Test courtesy of US Army Research Laboratory (ARL)







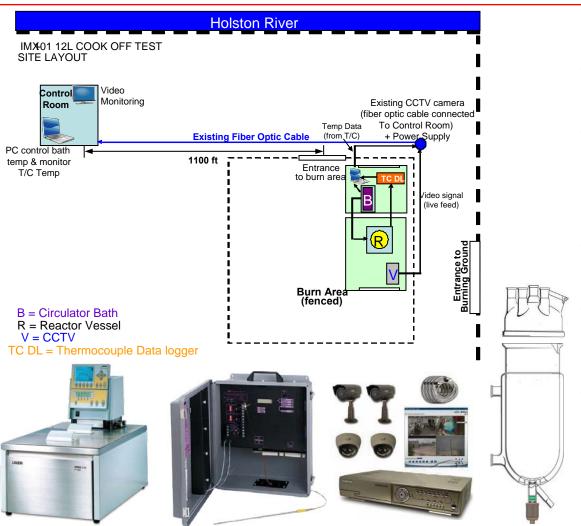
Objective

- Determine whether the scaling effect for T_c, as predicted by both the F-K and Semenov Models exist for non-traditional melt pour formulation IMX-101 in a larger configuration
 - Compare T_c between Small Scale, 1L, and 12L Cook Off Test
 - Demonstrate that thermal event is independent of kettle size
- 12 Liter Cook Off Test
 - Increase amount from 1 Liter Cook Off Test by factor of 12
 - Utilize 15 liter jacketed reactor with geometry closer to production melt kettles
 - Heat at rate of 3.3°C/hr





12 Liter Cook Off Test Site Layout

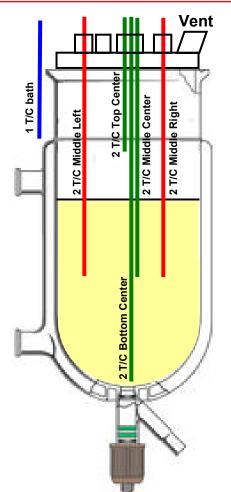


- Control Room located 1100 feet from actual test site
- All equipment must have remote capabilities
 - Data logger, CCTV, heating bath
- Tap into existing power and fiber optic network
- Containment of test vessel
 - 15 Liter reactor separate from other equipment
- Cannot enter test site upon start of test





Thermocouple Placement













Test Setup













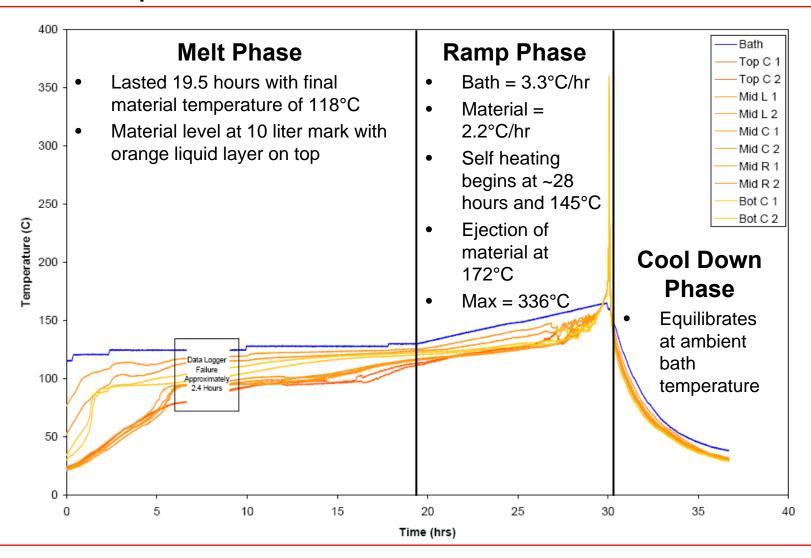








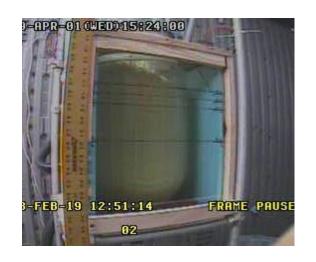
Thermocouple Data







Melt Phase







Start of Melt Phase	Middle of Melt Phase	End of Melt Phase
0 Hours into test	8.5 Hours into test	19.5 Hours into test
Bath Temp = 115°C	Bath Temp = ~124°C	Bath Temp = 130°C
Material Temp = 35°C	Material Temp = ~98°C	Material Temp = 118°C







Ramp Phase (Prior to 29 Hours)







Early in Ramp Phase	Middle of Ramp Phase	Late in Ramp Phase
20.5 Hours into test	25.5 Hours into test	28.5 Hours into test
Bath Temp = 134°C	Bath Temp = 150°C	Bath Temp = 160°C
Material Temp = 120°C	Material Temp = 130°C	Material Temp = 144°C







Ramp Phase (29 Hours)







Smoking Start	Self Heating at ~3x Rate	Beginning of Ejection
29.1 Hours into test	29.5 Hours into test	29.9 Hours into test
Bath Temp = 162°C	Bath Temp = 163°C	Bath Temp = 164°C
Material Temp = 150°C	Material Temp = 158°C	Material Temp = 172°C





Ejection of Material













18:32:04	18:32:57	18:33:21	18:33:23	18:33:46	18:34:04
Bath	Bath	Bath	Bath	Bath	Bath
164.5°C	164.4°C	164.4°C	164.5°C	164.9°C	164.5°C
Material	Material	Material	Material	Material	Material
170.7°C	171.5°C	171.6°C	171.9°C	172.2°C	172.7°C







Temperature Max/Camera Obscuration







Maximum Material Temperature	Obscuration of Camera	Obscuration of Camera
30.0 Hours into test	30.1 Hours into test	30.1 Hours into test
Bath Temp = 165°C	Bath Temp = 160°C	Bath Temp = 160°C
Material Temp = 336°C	Material Temp = 252°C	Material Temp = 252°C







Cool Down Phase







Camera 1	Camera 2	Camera 4
30.8 Hours into test	30.8 Hours into test	30.8 Hours into test
Bath Temp = 123°C	Bath Temp = 123°C	Bath Temp = 123°C
Material Temp = 106°C	Material Temp = 106°C	Material Temp = 106°C







Post Test Observations

Shed

- Coated with yellow powder (inside and outside)
- Considerable amount of ejected material with splatter on walls
- No visual signs of burning or damage



- Coated with material and undamaged
- Thermocouples
 - Still functioning
- Material
 - Post test analysis indicates ejected material is primarily IMX-101













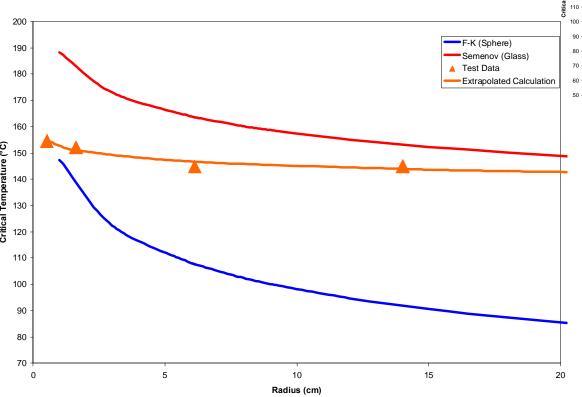


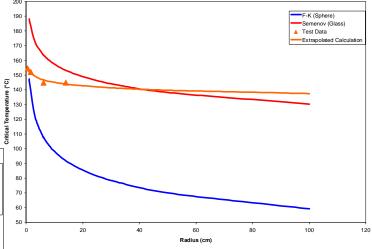




Experimental Data vs. Predictions

 Test data holds to a shallow curve compared to F-K and Semenov models





- T_c is similar at all sizes
 - Constant at 145°C ± 5°C
- Indicates predicting T_c of IMX–101 may not follow traditional models







Conclusions

- 12 Liter Cook Off Test
 - IMX–101 displayed start of self heating at 145°C and <u>non-catastrophic</u> thermal event at 172°C
 - Results similar to results from 1 Liter Cook Off Test and Small Scale Cook Off Testing
- IMX-101
 - Critical Temperature prediction based on the F-K and Semenov model did not apply to IMX-101
 - Scaling effect not applicable
 - Thermal event resulted in ejection of hot material from vessel, a <u>non-catastrophic</u> event







Conclusions (cont)

- Thermal Hazards
 - Conservative estimates obtained from F-K and Semenov models
 - IMX-101 <u>proven to be safe</u> to process/load on large scale with appropriate control measures
 - Official statement from Energetic Materials Qualification Board:

"The EMQB considered the results of both tests and has affirmed an acceptable safety margin of ≥40°C over the typical IMX-101 processing temperature..."

"The EMQB Explosives Subcommittee concurs that IMX-101 is safe to handle, process, and load in large production/loading environments"







Acknowledgements

BAE Systems/HSAAP

- Mr. Brian Alexander
- Mr. Virgil Fung
- Mr. Jim Owens
- Mr. Curtis Teague



- Mr. Charlie Patel
- Mr. Crane Robinson
- Dr. Kenneth Lee
- ARL
 - Dr. Brian Roos



















Questions?

FITS Finnish IM Technology Study 2009 IM/EM Technology Symposium

TUCSON, AZ

Kosti Nevala
Project Manager
Explosive Manager
Patria Land & Armament
Finland

Content

Patria

- Background
- Organisation
- Work breakdown
- Working methods
- Deliverables
- Conclusion

Background

Patria

- Finnish Defence Forces IM Policy
- Defence industy ambitions
- Global tendency to IM

Patria

Organisation

Prime: Patria

Partners in cooperation:









=(FDF Technical Research Center)



FY-COMPOSITES

Kosti Nevala

Patria

Work Breakdown

- Projectile related technologies
- Charge related technologies
- AEC's (Army Engineering Charges)
- Logistic issues

→10 Working groups

Kosti Nevala

Working methods

- Literature searches
- MSIAC technical questions
- Databases
- RFI's
- Visits
- Modelling
- THA, CBAM, SAS
- Testing

System engineering approach

Kosti Nevala

Patria

Patria

Deliverables

- IM state of the art summary report (Jan. 2008)
- Lifecycle issues with IM & opportunities to cooperation (Jun. 2008)
- In-depth analysis of IM status of 120mm mortar, 155mm artillery, 30mm MP-T ammo and AP mine replacements (Nov. 2008)
- Final report (Jun. 2009)

Kosti Nevala

Patria

Conclusion

- Unique project organisation
 - Lessons learned
- Groundwork, no development project
- Potential IM-solutions for specified products
- IM-technology gaps identified
- Opportunities for cooperation identified
- Existing IM-situation (Finland, global) report





2009 IM & EM Technology Symposium

IM Response Descriptors — An Update for Assessment Processes

Presenter:

Thomas Eich, BWB, Germany

Co-authors:

Bernie Halls, MSIAC Serge Bordachar, DGA, France Michael Sharp, DES/WPNS, UK Thomas Swierk, NSWC, US



Overview

MSIAC sponsored technical meetings in Jun & Dec 2008 to review & update IM response descriptors.

Participants:

Herve Benard (FR)

Jean-Pierre Gueguen (FR)

Stuart Blashill (US) Bernie Halls (MSIAC)

Serge Bordachar (FR) Klaus Kupzik (GE)

Felix Daguise (FR) Gerhard Schaad (GE)

Eric Deschambault (US) Michael Sharp (UK)

Thomas Eich (GE) Steven Struck (US)

Brian Fuchs (US) **

Tom Swierk (US) **

Yanick Garcia (FR) Julian Taylor (UK)

Regis Guegan (FR) Ken Tomasello (US)

** Meeting chairman



Why this update? Rationale for change

- * Current definitions can sometimes lead to confusion & subjectivity
- <u>Criteria application</u>: the munition behavior and particularly its fragmentation process can vary among different munition types, such as an artillery shell or a solid rocket motor. This complicates the use of a common behavioral criteria. Based on effects criteria, munition size, type and configuration all have a major effect on descriptor use for assessments.
- <u>Difficulties in response type assignment</u>: Types I III (for artillery shells), Types III V (for SRM) are more influenced by the different nature and the combination of criteria based on munition behavior (chemical energy release, fragmentation) and pure environmental effects (thermal flux, overpressure, fragment projection).
- <u>Lack of precision</u> in some measurement requirements: How do we address the strongly directional effects for air blast overpressures? Location in the Mach zone? Position of radiative heat flux gages, and overpressure measurement uncertainties?



<u>Additional Rationale</u>

- * A need to better assess collateral damage and to provide data for platform vulnerability studies.
- <u>1997-1998 NIMIC workshops</u> Identified missing link between response descriptors and damage (weapon platforms, ships, etc.). Descriptors focused both on chemical reactions of energetic materials and hazards induced by the munitions reactions. They are used as an input for vulnerability, IM and hazard class assessments.
- <u>Hazard division assessments</u> traditionally address the concept of damage on systems and personnel but have their own inherent limitations for operational platform vulnerability assessments (hostile environment and THA not included in the UN classification scheme, SRM and gun propellant tests do not address detonability (exception: TB 700.2, US). No international harmonization.



Objective of Technical Meetings

Review, examine & offer recommendations to update the Response Descriptors listed in AOP-39 and other documents for relevance to IM & HC assessments. This should improve the robustness of assessing the IM signature of a munition.

Examine current

IM Response Descriptors cited in:

STANAG 4439

AOP-38 & 39

TB 700-2

MIL-STD-2105 (US)



Formulate new, standardized IM Response Descriptors for future IM & HC assessments



Background

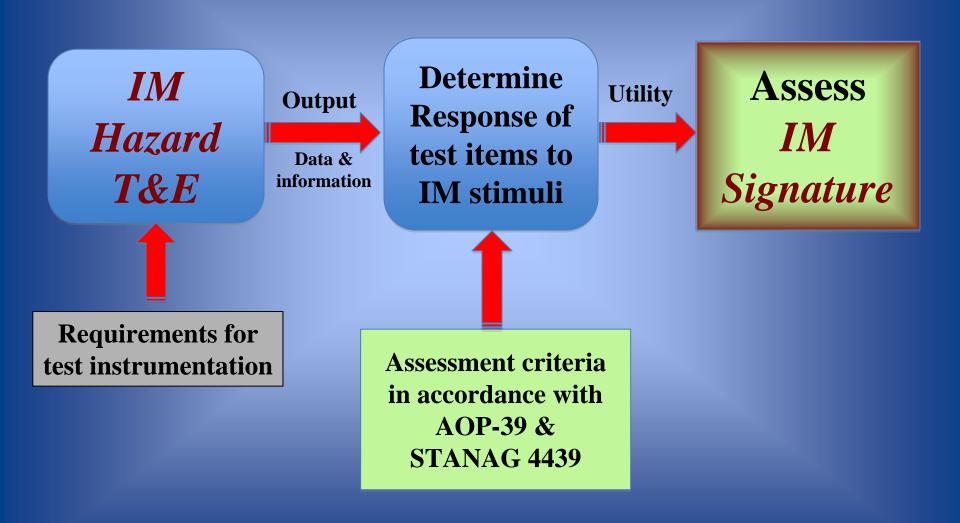
1997 NIMIC Workshop topic: IIM Testing & Response Descriptors

Summary of Recommendations

- Identified threshold criteria for qualitative vs. quantitative descriptors:
 - Reaction type (current method) descriptors have limitations
 - Type descriptors concentrate only on chemical reaction of energetic materials and don't address energy release to surroundings (collateral damage).
 - This is not in concert with the IM goal of minimizing the probability of inadvertent initiation & the severity of subsequent collateral damage.
- Identified <u>Levels of Response</u> to move closer to user needs (safety authority, risk assessor, etc.) and to accommodate HC divisions.
- Levels of Response replace the Reaction types where munitions response is characterized by damage levels at various distances from point of origin.



Response Descriptor Utility





Utility for IIM Signature

Responce descriptors are initially used for authoratative assignment of reaction types to individual IM hazard and Hazard Classification test results.

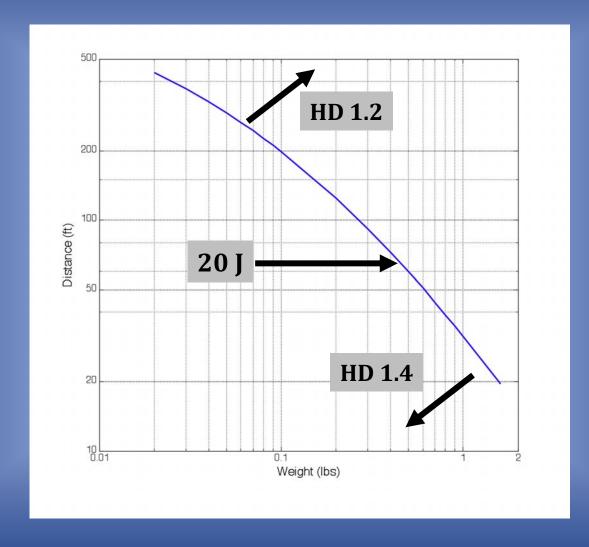
- IM test results contribute to the IM assessment information & report (i.e., the total *Body of Evidence*) per AOP-39
- Response descriptors used to identify assigned reaction types are used in the IM Signature display per AOP-39.



Summary of Principal Recommendations from the Technical Meetings

- Identify Primary & Secondary evidence for each reaction type
 - Primary evidence must always be observed and would be definitive of the reaction type
 - Secondary evidence could be observed, but its lack would not preclude that reaction type
- Redefined a "hazardous fragment" for Type IV and TypeV reactions
 - Used 20J as energy threshold vice current 79J level.
 - This is consistent with the UN "Orange Book" that distinguishes HC 1.2 vs. 1.4
- Clarified the definition of a "propulsive reaction" as a subset of a Type IV reaction.
- Deleted blast pressure level of 50mbar at 15m for Types III, IV and V.
- Recommended calibration tests, when practical, as comparative (baseline) evidence.
- Ensured that a Type VI (no reaction) level is defined and included





Fragment energy relationship taken from Figure 5-17 of TB 700-2 (30 Aug 08)



Example:

Type I Detonation

- Primary evidence: Must include
 - Shock wave with magnitude and timescale = calculated or measured value
 - Rapid plastic deformation of the metal casing with extensive high shear rate fragmentation
- **Secondary evidence:** May include
 - prompt consumption of all energetic material
 - Perforation, fragmentation and/or plastic deformation of witness plates
 - Ground craters corresponding to the amount of energetic material in the munition



AOP -39 (edition 2), Annex I (current version)

Response Type	Munition Behaviour		Effects			
	Energetic Materials	Case	Blast	EM projection	Fragment projection	Other
l (detonation)	Supersonic decomposition	Very fast plastic deformation; Total fragmentation	Intense shock wave; Damage to neighboring structures	All the materials react	Perforation, plastic deformation or fragmentation of adjacent metal plates	Large craters in the ground
II (partial detonation)	Supersonic decomposition	Partial fragmentation with large fragments	Intense shock wave; Damage to neighboring structures	All the materials react	Perforation, plastic deformation or fragmentation of adjacent metal plates	Large craters in the ground (proportional to amount of detonating EM)
III (explosion)	Fast combustion of confined material; local pressure build-up	Violent breaking into large fragments	Blast effect < Type I; Damage to neighboring structures; P > 50 mbar at 15m	Scattering of burning EM; Risk of fire	Long range projection; damage to metal plates (breaks, rips, cuts)	Small craters in the ground
IV (combustion/deflagration)	Non-violent pressure release	Breaks but does not fragment into more than 3 parts; expulsion of end caps; gases release through opening	Blast effect limited to P < 50 mbar at 15m	Scattering of EM; Risk of fire	Expulsion of end caps and large structural parts; no significant damage	Damage caused by heat and smoke; propulsion of unattached sample
V (burn)	Combustion	Splits in a non-violent way; smooth release of gases; separation of ends	Blast effect limited to P < 50 mbar at 5m	EM remains nearby (<15m)	Debris remains in place except covers; no fragment of more than 79J or > 150g beyond 15m	Heat flow < 4 kw/m ² at 15m



AOP -39 (edition 2), Annex I (revised version)

Response Level	Munition Behaviour		Observed or Measured Effects			
	Energetic Materials (EM)	Case	Blast	EM projection	Fragment projection	Other
Type I (detonation)	(P) Shock wave with magnitude & timescale = to a calculated value or measured value from a calibration test	(P) Rapid plastic deformation of the metal casing contacting the EM with extensive high shear rate fragmentation	Prompt consumption of all EM once the reaction starts	All of the EM reacts	Perforation, fragmentation and/or plastic deformation of witness plates	Ground craters of a size corresponding to the amount of EM in the munition
Type II (partial detonation)	(P) Shock wave with magnitude & timescale < than that of a calculated value or measured value from a calibration test	(P) Rapid plastic deformation of some, but not all, of the metal casing contacting the EM with extensive high shear rate fragmentation	Intense shock wave; Damage to neighboring structures	Scattered burned or unburned EM	Perforation, plastic deformation and/or fragmentation of adjacent metal plates	Large craters in the ground (proportional to amount of detonating EM)
Type III (explosion)	(P) Rapid combustion of some or all of the EM once the munition reaction starts	(P) Extensive fracture of metal casings with no evidence of high shear rate fragmentation resulting in larger and fewer fragments than observed from purposely detonated calibration tests	Observation or measurement of a pressure wave with peak magnitude << than and significantly longer duration that of a measured value from a calibration test	Significant long distance scattering of burning or unburned EM; risk of fire	Long range projection; damage to metal plates (breaks, rips, cuts)	Small craters in the ground
Type IV (deflagration)	(P) Combustion of some or all of the EM	(P) Rupture of casings resulting in a few large pieces that might include enclosures or attachments.	May include a longer reaction time than would be expected in a Type III reaction	Scattered burning or unburned EM; risk of fire	(P) At least one piece (casing, enclosure or attachment) travels beyond 15m with an energy level > 20J based on the distance/mass relationship used for HC ¹ .	(P) There is no primary evidence of a more severe reaction and there is evidence of thrust capable of propelling the munition beyond 15m. Damage caused by heat and smoke.
Type V (burn)	(P) Low pressure burn of some or all of the EM	(P) The casing may rupture resulting in a few large pieces that might include enclosures or attachments.	Some evidence of insignificant pressure in the test arena and for a rocket motor a significantly longer reaction time than if initiated in its design mode.	(P) A small amount of burning or unburned EM relative to the total amount in the munition may be scattered, generally within 15m but no farther than 30m>	(P) No item (casing, enclosure or attachment) travels beyond 15m with an energy level > 20J based on the distance/mass relationship used for HC ¹ .	(P) No evidence of thrust capable of propelling the munition beyond 15m
Type VI (no reaction)	(P) No reaction of the EM without a continued external stimulus	(P) No fragmentation of the casing or packaging greater than that from a comparable inert test item.	None	(P) Recovery of all or most of the unreacted EM with no indication of a sustained ignition.	None	None



Process to implement changes: **Deferred / rejected MSIAC** proposal Report to IM Response for AOP-39 & **MSIAC & STANAG 4439 Descriptors** participating updates submitted Technical mtgs nations to SG3 & SG5 accepted **Identify knowledge gaps** & formulate plan to resolve AC-326 to review **Recommendations Member nations** NOT approve/ratify approved approved changes & implement as part of their **STOP** national policies



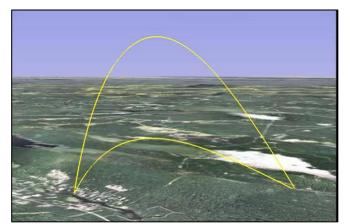
Analysis of Throw Distance Produced by a Sub-detonative Munition Response

E.L. Baker, J. Grau, J.A. Cordes, E. Vazquez, T. Madsen, D. Suarez, Y. Wu, D. Carlucci and D. Carra



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Dr. Ernest L. Baker IM Technology Lead U.S. Army ARDEC





Outline



- Introduction
- Incident Description
- Technical Analysis
 - >>> Fragment Physical Analysis
 - High Rate Continuum Modeling
 - Aeroballistics Analysis
- Technical Findings
 - Similar Events
 - Root Cause
- Conclusions



Introduction



- IM type III response (explosion): "Metal cases are fragmented (brittle fracture) into large pieces that are often thrown long distances".
- The interpretation of "long distances" has recently been a question of concern to ARDEC.
- Discussions with the IM technical community have indicated that quite often an interpretation is that this references distances significantly greater than 15 meters, one of the criteria used to differentiate between type V and IV and distances of a hundred meters or more have been observed.
- Be aware: Fragment throw to much longer distances, on the order of at least two kilometers is possible and has occurred for the case of sub-detonative munitions response.
- ▶ The statistical occurrence of such long fragment throw distances for sub-detonative munitions response is not currently known.



Incident Description



Tests in support of Explosive Ordnance Disposal (EOD) research and development activity. The purpose of the tests was to develop methods for disposal of unexploded munitions. Projectile was purposely subjected to non-standard initiation using a shaped charge directed at the projectile.

- Testing on unfuzed, comp B loaded M107, 155mm, artillery projectile
- 1st shaped charge fired into M107 base
- No initiation/ignition of M107
- 2nd shaped charge fired into sidewall
- Sub-detonative response
- Generates 1lb 14oz fragment
- Fragment travels ~1824 meters (5984 ft)
- Greatly exceeds established safety distance zone (SDZ)





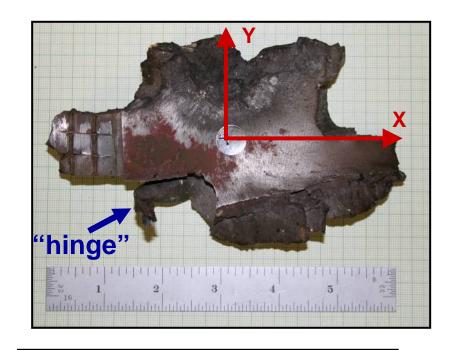


Fragment Analysis



- Metallurgical tests of the fragment
 - >> 1046 alloy, failed in shear with a tensile component (hinge)
- Fragment Solid Model
 - laser scan of the fragment
 - generated CAD solid model
- Physical Properties
 - Calculated and measured the fragment's physical properties

CAD physical properties		
Mass	1.902	Lbs
lxx	1.005	lbs-in. ²
lyy	3.264	lbs-in. ²
Izz	4.118	lbs-in. ²



measured physical properties			
Mass	1.854	Lbs	
lxx	1.011	lbs-in ²	
lyy	3.183	lbs-in ²	
Izz	3.995	lbs-in ²	

Close agreement: difference attributed to small voids

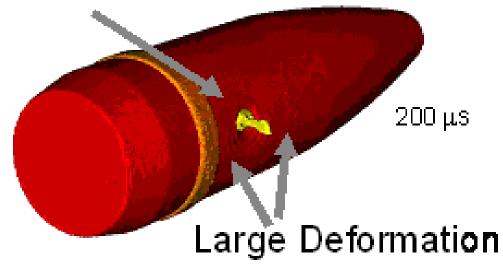


High Rate Modeling ALE3D

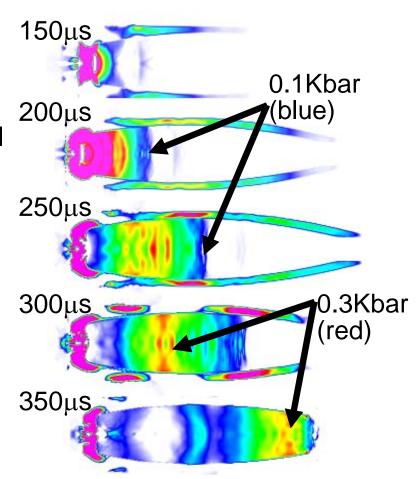


- Modeled shaped charge shot into base
 - damaged projectile base not sidewall
 - damaged cast Comp-B explosive
- Modeled shaped charge shot into sidewall
 - → did not form large fragment
 - significant momentum transfer

Case perforation



M107 Shaped Charge Attack



Pressure profile plots from SC base attack

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



High Rate Modeling ALE3D

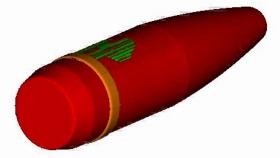


DB: deflag_048.00000 Cycle: 0 Time:0 Filled Boundary Var: material

-1 steel_1 -2 steel_2 -7 copper_7



DB: deflag_096.00001
Cycle: 1 Time:0.001
Filled Boundary
Var. material
-1 steel_1
-2 steel_2
-3 air_3
-5 compb_5
-6 air_6
-7 copper_7
-8 air_8



user: dsuarez Tue Apr 14 10:25:00 2009

Detonation (fragment breaks-up)

user: dsuarez Fri May 908:07:182008

Deflagration

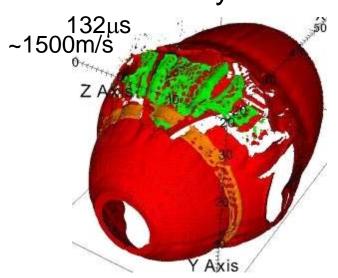
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



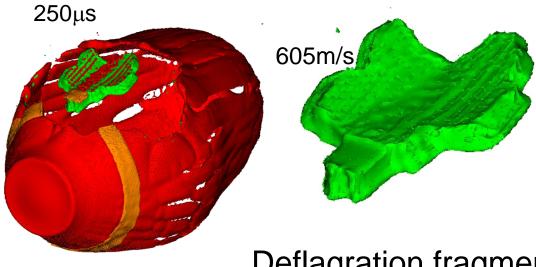
High Rate Modeling ALE3D



- Explosive response modeling
 - high order detonation generates smaller fragments
 - >> sub-detonation response formed large fragment
 - >> sub-detonation response can invert fragment
 - >> sub-detonation response produces a lower initial velocity



Detonation (fragment breaks-up)



Deflagration

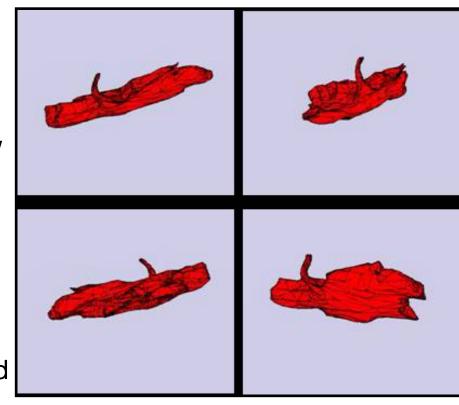
Deflagration fragment (upward curvature)



Aeroballistics Analysis



- Aeroballistics Analysis
 - characterized fragment's aeroballistics properties
 - established range of possible fragment trajectories
 - established fragment achieved low drag, edge on orientation
 - determined a significant spin rate was required to maintain low drag edge on orientation
 - >> tumbling fragment could not have achieved this range even with a high order detonation
 - supports initial velocities generated from sub-detonative response

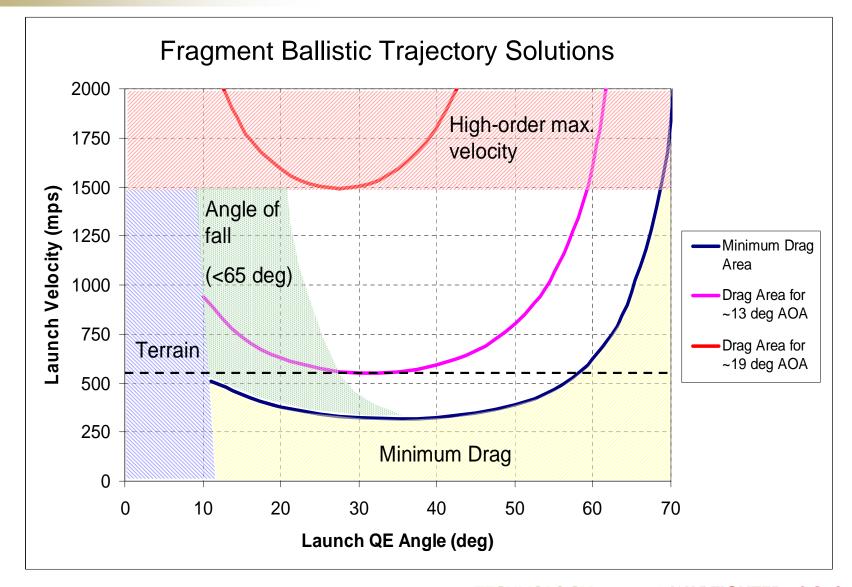


Flight Simulation Snapshots



Aeroballistics Results

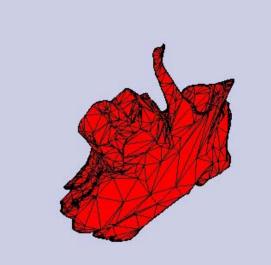


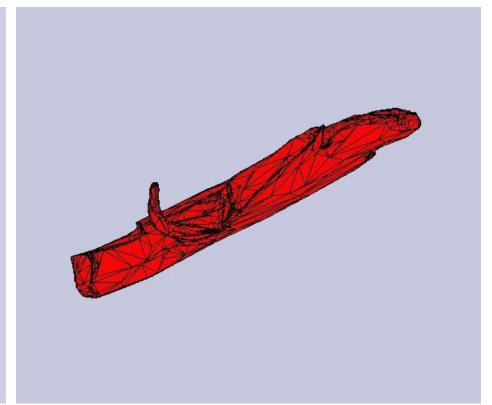




Aeroballistics Analysis







Lower Spin Rate (fragment tumbles)

Higher Spin Rate (fragment stable)

Standard assumption for fragment aeroballistics calculations is random orientation (fragment tumbles)



Technical Findings



- During investigation, learned of and conducted evaluation on other fragments exceeding established HFDs
 - >> Only 4 identified events
 - >> 2 of the events with fragments that look fairly similar to the ARDEC fragment: large flat fragments
 - Non-standard initiations have caused large flat fragments
 - Standard initiation has also caused large fragments ...but not as large as non-standard initiation

Fragment



large, fairly flat



Technical Findings



- 3 Main factors (high likelihood)
 - Reaction within the M107 was deflagration, creating a relatively large and aerodynamically stable fragment (A plastically yielding "hinge" held onto a large, flat fragment reducing likelihood of tumble)
 - Fragment flew aerodynamically-stable rather than tumbling
 - Generally accepted methods for calculating HFD assume fragments tumble rather than fly aerodynamically stable



Conclusions



- IM testing commonly produces sub-detonative muntions response: fragment throw to much longer distances than would be predicted using established hazard fragment distance (HFD) analysis is possible
- Aeroballistics analysis determined fragment was capable of achieving the demonstrated range (1824 meters, 5,984 ft) and greater
 - ▶ low drag, edge on orientation with spin required
 - many possible combinations of launch quadrant elevations and velocities
- Sub-detonative response
 - >> formed large fragment with hinge
 - >> provided spin to stabilize fragment orientation
 - >> provided required fragment initial velocity







DoD Ordnance Technology Consortium (DOTC)



DOTC Vision



An integration of Government, Industry, and Academia into a single enterprise executing Joint and co-funded initiatives, sharing and developing goals and objectives, resources and assets, and utilizing existing personnel, facilities and equipment



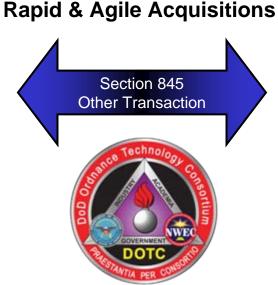
DoD Ordnance Technology Consortium (**DOTC**)

GovernmentLaboratories



- OUSD (AT&L) LW&M
- Department of The Army
- Department of the Navy
- Department of the Air Force
- Department of Energy
- Special Operations Command
- Other Agencies and Departments

National Warheads & Energetics Consortium





- Defense Contractors
- Traditional & Non-Traditional
- Academic Institutions
- Not-for-Profits Organizations

DOTC PER CONTROL OF THE PER CONT

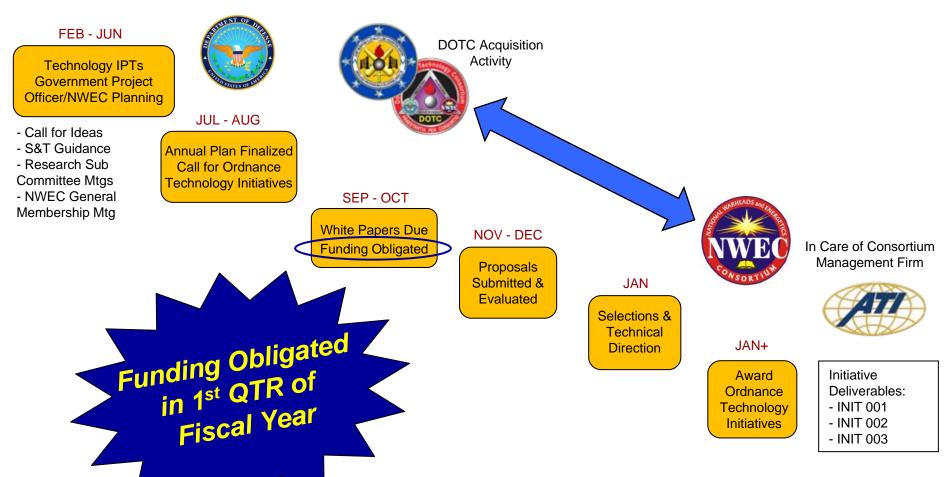
Mission

- DOTC's mission is to demonstrate feasibility and/or the transition of Advanced Explosives, Propellants, Pyrotechnics, Warheads, Fuze/Sensors, Demil, Joint IM and Enabling Technologies through Prototype Initiatives
 - Rapid technology transfer to the Warfighter
- Advocates a critical mass of world-class technologists to meet the National Defense needs
- Leverages government, private industry and academia R&D resources (funding, personnel, facilities and equipment) to maximize return on investment
 - Promotes nontraditional defense contractor involvement
 - Promotes innovation
- STEM program is an integral part of OSD's Educational Outreach Program in providing an ongoing source of scientific and engineering talent for government R&D labs
 - Maintain future US Armed Forces battlefield superiority



Single Point Contracting Model

Funding Obligation and Project Award...





FY10 Schedule

Call for Good Ideas/Annual Plan Updates	MAR 09
SubCommittee Meetings	MAY 09
NWEC General Membership Meeting	15-16 JUL 09
Finalize Annual Plan	30 July 09
DOTC Executive Committee meeting	17 AUG 09
Request for Ordnance Technology Initiatives	24 AUG 10
White Paper Submittal to ATI	15 SEP 09 (noon EST)
White Papers Sent to Government	17 SEP 09
White Paper Feedback to NWEC Members	06 OCT 09
Proposals Received by ATI	18 NOV 09 (noon EST)
Government Evaluation of Proposals	21 DEC 09
Technical Direction & Initial Awards	JAN 10



OT's Provide a Better Way To Do Business

- Break-through technologies are more accessible to DoD labs
 - Small businesses and academia team with industrial base suppliers
 - Identify and provide industry technology gap visibility
- Innovative business relationships and partnerships
- Flexibility to better manage R&D programs and meet technical objectives (requirements continuously evolve in R&D)
- More opportunities to obtain and/or leverage funding and resources
- Managers are able to allow engineering staff focus on technical details of projects rather than administration details of contracts



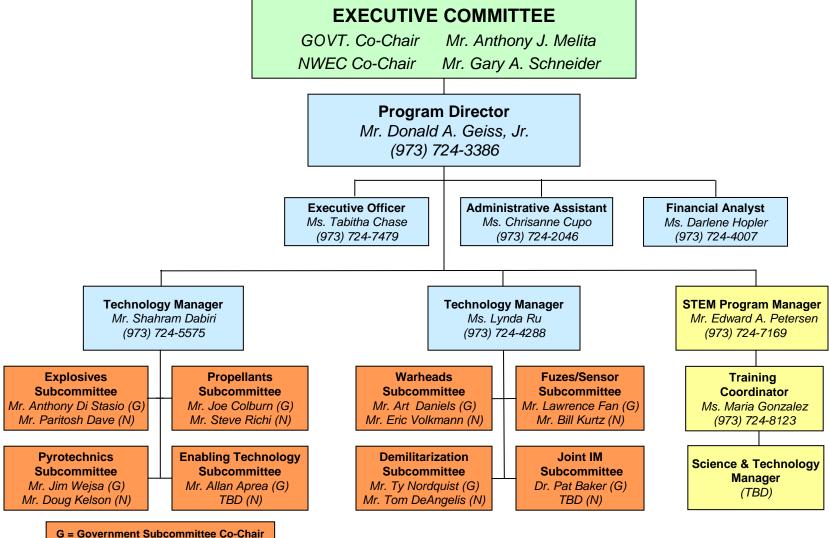
TATB

- Collaborative effort to establish and demonstrate a US manufacturing capability for TATB
- A joint working group was formed consisting of technical experts from the Air Force, Army, Department of Energy, OSD, and the Navy
- Co-funded by Air Force, Army and Navy



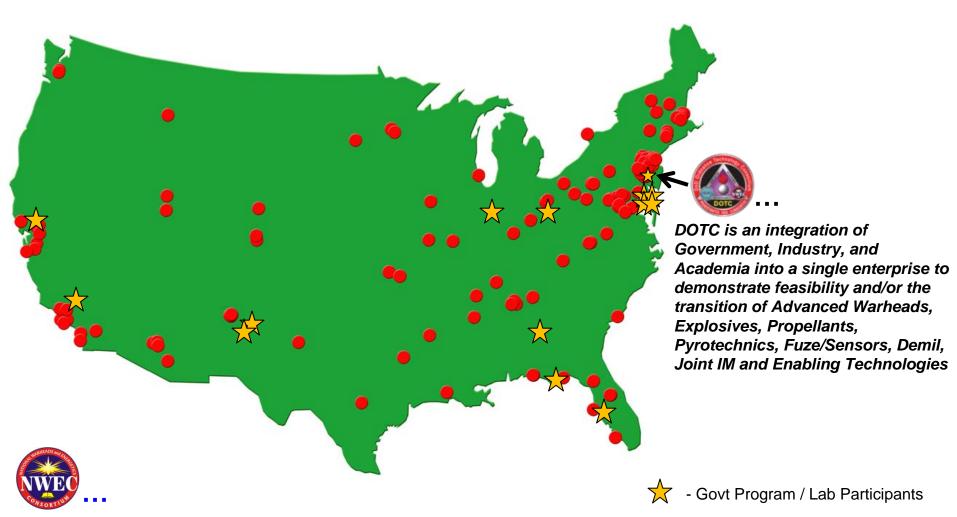
N = NWEC Subcommittee Co-Chair

DOTC Management Organization





Broad Based Participation



Over 120 member companies performing innovative R&D, needed to develop and transition new technologies into weapon systems to support the advancement of future war fighting capabilities.

10

- Industry participants



NWEC Traditional Companies

Accurate Energetics Systems LLC

Aerojet

American Ordnance LLC

American Systems Corp.

Applied Energetics

Applied Research Associates

Armtec Defense Products-

Esterline Defense Group

ATK Advanced Weapons

ATK Launch Systems

Axsun Technologies, Inc.

BAE SYSTEMS.

Battelle

Cartridge Actuated Devices, Inc.

Chemical Compliance Systems, Inc.

Concurrent Technologies Corporation

Day & Zimmermann, Inc.

DE Technologies, Inc.

Dindl Firearms Manufacturing, Inc.

Dynamic Systems & Research Cotp

Dynetics, Inc.

Eagle Picher Technologies, Inc.

El Dorado Engineering Inc

Electronics Development Corp.

Energetics Material & Products

Ensign-Bickford Aerospace

& Defense Company

Frontier Performance Polymers Corp.

General Atomics

General Dynamics Ord & Tactical Sys

General Sciences, Inc.

Goodrich Sensors & Integrated Systems

Hi-Shear Technology Corp.

Honeywell International, Inc.

Infoscitex Corp.

Kaman Aerospace Corp

Kilgore Flares Co. LLC

Lasertel, Inc

L-3 Communications - BT Fuze

L-3 Communications – KDI.

Lockheed Martin Company

Malcolm Pirnie, Inc.

Material Processing and Research, Inc.

Mecar USA, Inc

Medico Industries, Inc.

Missouri University of Science and

Technology

MSE Technology Application, Inc.

NAMMO Talley, Inc.

National Technical Systems, Inc.

New Jersey Institute of Technology

Northrop Grumman Space Technology

Pacific Scientific Energetic Materials Co.

Planning Systems, Inc.

Raytheon Company

Reynolds Systems, Inc.

SAIC

SAIC – Systems Engineering & Technology

SciTech Services, Inc.

SCRA

Stevens Institute of Technology

Subsystems Technologies, Inc.

Syntronics, LLC

Systima Technologies, Inc.

Tanner Research, Inc.

Technikon LLC

Teledyne RISI

Texas Tech University

Textron Systems Corp.

The Boeing Company

The Ex One Company

The Pennsylvania State University

The Timken Company

Touchstone Research Lab., LTD

TPL, Inc.

Universal Technical Resource Services, Inc.

University of Denver

University of Florida

University of Maryland

University of Mississippi

University of Texas at Austin

UXB International, Inc.

Veritay Technology, Inc.

West Virginia University Research Corp.

11



NWEC Non-Traditional Companies

Action Manufacturing Company

AdvancedMaterials &

Manufacturing Technologies, LLC

Ahura Corporation

Applied Sonics, Inc.

BEC Manufacturing Corporation

Bennington Microtechnology Center

BlastGard International, Inc,

CarboMet LLC

CAE Solutions Corp

CLogic, LLC

Combustion Propulsion and Ballistic

Technology Corporation

Engineering and Management Executives, Inc.

Erigo Technologies, LLC

FED-COMM USA, Inc.

Folsom Technologies

G. Schneider & Associates, Inc.

Gunger Engineering

Hittite Microwave Corp.

HT Microanalytical Inc.

Imperial Machine & Tool Company

Innovative Technologies International

Latrobe Specialty Steel Company

Milli Sensor Systems & Actuators, Inc.

Mixed Signal Integration

Nanomaterials Discovery Corp

nanoPrecision Products, Inc.

NASCENTechnology

Nuvotronics

Pendulum Management Co., LLC

Plasma Processing Inc.

Polestar Technologies Inc.

Polymer Processes, Inc.

QuesTek Innovations LLC.

Safety Consulting Engineers

Savit Corp.

SMH International, LLC

Special Devices, Inc.

Stanley Associates

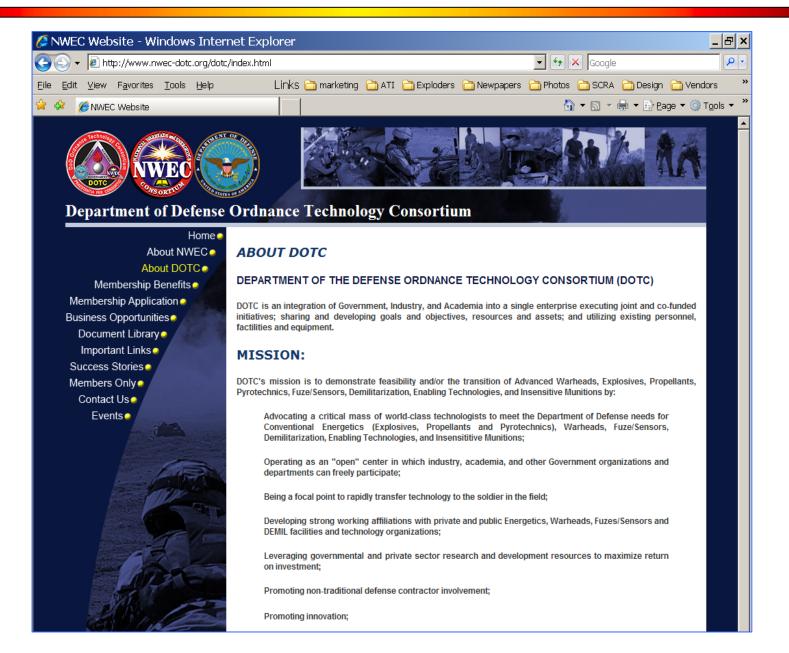
STG Inc.

Tanenhaus and Associates, Inc.

Thermal and Mechanical Technologies



DOTC/NWEC WebSite





Take Away

- The DOTC OTA (FY09-FY16, \$700M) is established and available to obligate funding
- Better collaboration among Government labs
 - Engagement of more DoD/DOE labs
 - Leveraging established DoD IPT processes
- DOTC supports partnerships, use of non-traditional contractors and education outreach
- DOTC provides a focal point to rapidly transfer technology to the Warfighter
- Visit web site at <u>www.nwec-dotc.org</u> for additional information





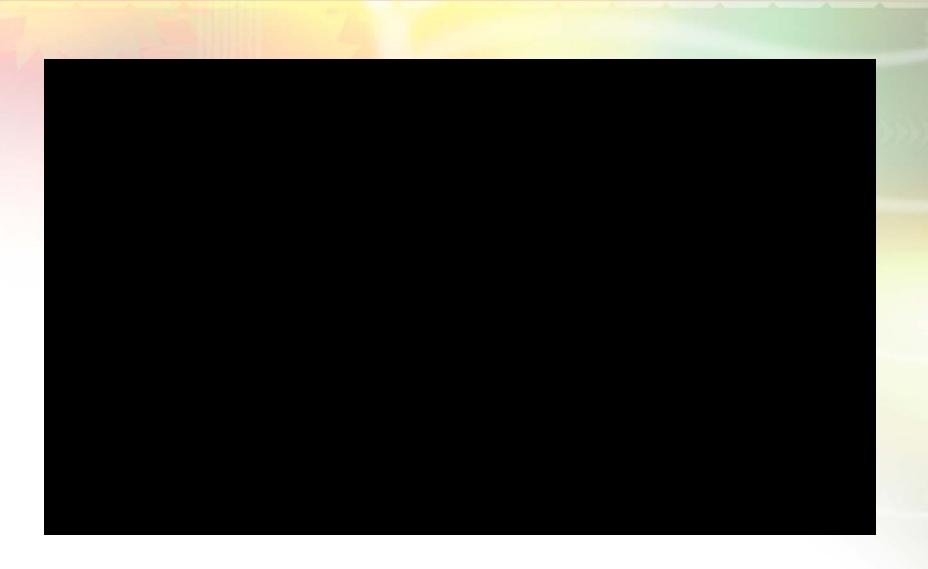


System topics & considerations

- Setting the significance of IM & EM.
- Symposium topics bridge the IM & EM technologies.
- Knowledge points: connecting the development dots.
- Prime contractor system considerations.
- Tying it all together.

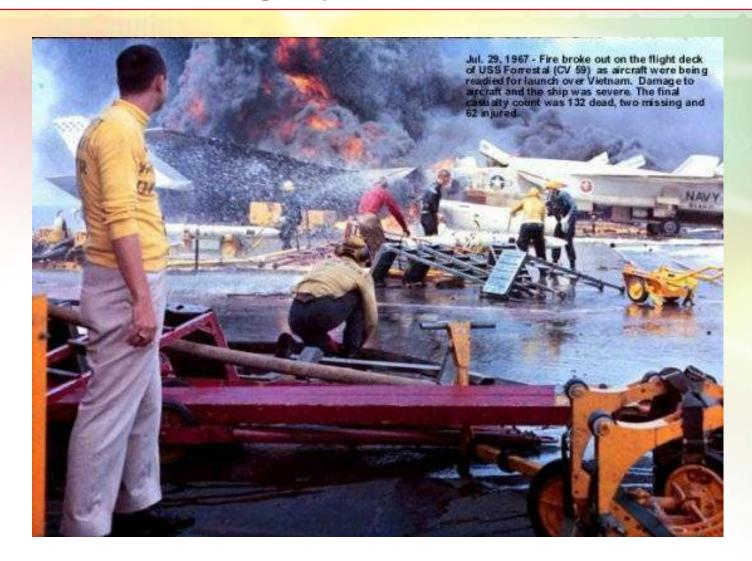


Why we get up in the morning...





But sometimes tragedy strikes...



IM & EM --- Protecting our war fighters through technology...

- This is a great symposium --- a broad range of key topics.
- Pushing the limits to drive maximum performance.
- Moving many solutions toward maturity.
- Exciting work in materials and modeling.
- Maturing developments in manufacturing and processing.

Knowledge points: Connecting the system engineering dots...



- Knowledge point 1: Resources and requirements match.
 - Technologies demonstrated in their intended environment.
 - Feasible preliminary product design.
- Knowledge point 2: Product design is stable.
 - Meets requirements, and cost, schedule, reliability targets.
 - 90% of engineering drawings completed.
 - Successful prototype demonstration of performance.
- Knowledge point 3: Manufacturing processes are mature.
 - Demonstrated manufacture within cost, schedule, and quality targets.
 - Critical manufacturing processes are under statistical control:
 - Repeatable, sustainable, and capable of consistent quality standards

Prime contractors are driven by IM & EM architecture and predictability...



- Balance of safety and logistics with performance and cost.
 - Energy, weight, structure, orientation, environment, enclosures, etc.
 - IM designs must synergize all constituents: igniters, EM, structures,...
- Technology and Manufacturing Readiness Levels.
 - Important indicators of development predictability.
- Modeling and simulation fidelity and verification processes.
 - Key for trade studies of compounds, shapes, and features.
 - Statistical validity assured through proper Design of Experiments.
- Synchronized technology development roadmaps needed.
 - Risk management and realism are essential.



Enjoy the Symposium!

- Watch and listen for how system drivers are addressed.
- Question and challenge the presenters on their premise.
- Assess the technologies for each knowledge point.
- Question the statistical basis of all claims.
- How ready are we for "prime time"?
- What will it take to get there?



Raytheon

Customer Success Is Our Mission











IM Overview





Patrick Touzé, MSIAC IMEMTS 2009











Munitions Standards Database (MSAS)

- NATO STANAGS and Allied Publications
- United Nations Standards
- European Standards
- Some ITOPs (DEU / FRA / GBR / USA)
- Some National standards (GBR, SWE, USA)
- Some international treaties impacting on munitions









Munitions Life Cycle regulations (Transport, Storage, Disposal,...) should be harmonized and ATO AC/326 implemented

AASTP-5 by NATO AC/326







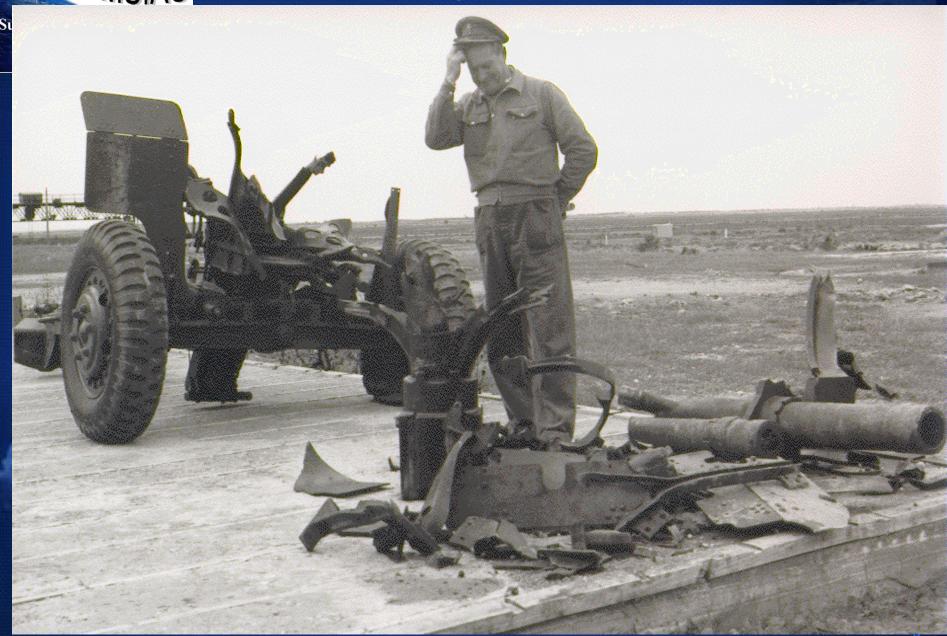


In Normal Environments, own munitions should remain safe and serviceable....





Or else...





In Extreme Environments, own munitions should react as mildly as possible, or not at all (Insensitive Munitions)...

STANAG 4439 by NATO AC/326

Personnel were burning excess artillery propellant bags, about 9 ft from the vehicle. The heat from the fire induced a low-order detonation of a 155 mm round that was in the vehicle.



MSIAC

Or else...

Supportin Munition Sa

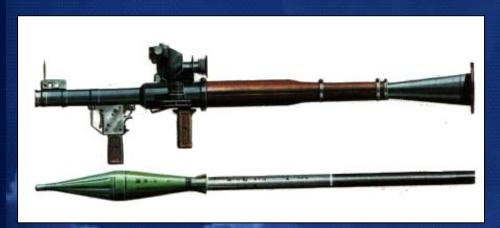


Kirkuk, Iraq, 02/06/04 – USAF Base Attack



As Extreme Environments become less and less unlikely, IM are more and more needed

IM is one of the Top Munitions Safety Priorities of AC/326 nations





RPG-7 available from 40+ Nations



Jane's IDR **Oct 05**

Insensitive munitions make the military less accident-prone

Western European and US policy makers are placing greater pressure on defence forces to use safer or 'insensitive' munitions to inhibit their inadvertent detonation. By Neil Gibson and Rupert Pengelley

Eric Deschambault, Patrick Touzé and Duncan Watt

Insensitive Munitions -A Key Aspect of Improved Munitions Safety





Two dramatic images on the flight deck fire onboard the aircraft carrier USS ENTERPRISE (CVN-65) on 14 January 1969. A MK-32 ZUNI rocket warhead attached to an F-4 PHANTOM was overheated by the exhaust from an aircraft starting unit and detonated. setting off fires and additional explosions across the carrier. The fire was brought under control promptly when compared with previous carrier flight deck fires, but 27 lives were lost, and an additional 314 people were injured. The fire destroyed 15 aircraft. and the resulting damage forced the carrier to put in for repairs, primarily to repair the flight deck's armored plating.

ving could also join given the consent of all NATO ageing issues. The technology remit is proparties). Denmark, and two Partnership for gressively being expanded beyond insensitiv-Peace nations, Finland and Sweden, fol-ity to through-life munitions safety". lowed in 2000-02. Not being major ammunition manufacturers, Denmark and Portugal regulations has been patchy since 1988, have since opted to cease their contributions nations having on a number of occasions to NIMIC's EUR1.5 million (USD1.86 mil- applied waivers for reasons of expediency or lion) annual budget, but their place is being necessity as a result of technology gaps.

According to Touzé, the application of IM

However, this is less and in the US, where IM regulations have become enshrined in law.

Tests may also be conducted differently, or their results interpre differently, in different nations. In some the use of modelling is regarded as appropriate to provide compliance, while in others there is an insistence on live tests at every stage. The designated evaluation tests and procedures sub-procedures, bullet variations, and so forth.

One of MSIAC's objectives is to harmonise these rules, Touzé noting "there is a preference for perfectly harmonised rules and test criteria but it will take time to get there".

The NATO standardi

IM taken by Germany, whose accession is general intent for IM was promulgated in In addition to the STANAG, Touzé told

types. The need therefore now is not so much IDR, each nation maintains its own national Italy, Fortugal, Spain and Australia (it raving for further technology as for implementation policies which may be more detailed (see been agreed in 1994 that non-NATO nations and fielding, which leads on to life-cycle and below). There are also differences between

vastation precipitated by the inadvertent explosion of munitions aboard an M992 upply vehicle at Camp Doha, the US Army's main base in Kuwalt, in the aftermath of ar. Note the presence of M829 depleted uranium anti-armour projectiles.

n the expected to be complete in October this year. 1998 and it has been ratified by 12-15 nations stally. The name change to MSIAC was made in to date. Associated with it is an application. December 2004. As explained by MSIAC document (AOP39) which sets out the Project Manager Patrick Touzé, "the technol- assessment and test methodologies. One of ogy for IM did not exist originally, hence the the original tests (shaped-charge jet spall creation of NIMIC. Now the technologies do impact) is being withdrawn. exist and are available for most ammunition





An IM Success Story - US - 2005

FCO	sco	ВІ	FI	SR

MK-82 mod 2 TP BLU – 111/B



IM on the market

IM Technology

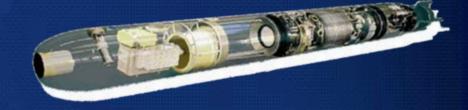
Customers



Compared IM Signature

Compared Performance

Compared Cost







Highlighted Land Systems

- 30-mm ammunition
- 40-mm 3P Round
- 60-mm Mortar (M720E1)
- 60-mm MAPAM
- 105-mm DPICM (M915)
- 105-mm Improved Ammunition (L50)
- Reactive Tile Armour for AFV
- Excalibur 155mm (XM982)
- 120-mm APFSDS (M829A3)
- DM63 for APFSDS-T 120mm
- TPCSDS-T 120mm training cartridge (XM1002)
- 120-mm cartridge (XM1028)
- 120-mm Mortar (M934A1E1)
- 155-mm Artillery Shell (LU-211M)
- Modular Artillery Charge System (MACS)
- Modular Artillery Top Charge Modules
- Modulares Treibladungssytem (DM72/92)
- 155-mm RH30
- Air Defence Missile VT1 01
- Anti-Personnel Obstacle Breaching System (APOBS)
- Formable explosive No. 3 Mk1
- Demolition block No. 4 Mk1
- Spider (XM7)











IM Gaps



- IM Technology MSIAC Workshop
 - Surveys to identify gaps
 - Preliminary MSIAC Workshop 11 May 2009: prioritize gaps according to users' needs
 - Main MSIAC Workshop in 2010
- IM "Enabling tools"
 - Harmonized, objective, scaleable, informative, relevant, environmentally friendly testing methods
 - Standardized and shared models and codes to predict energetic materials, components and munitions responses



IM Policy

- STANAG 4439 Ed.2 and AOP-39 Ed.2 promulgated on 9 Feb 2009 (ref. IMEMTS 2006, R. Guégan)
- Ongoing work to update AOP-39 again
- Proposal to modify IM Response Descriptors (ref. IMEMTS 2009, T. Eich), with impact on STANAG 4439









The need for IM is growing; let's eat this big technological challenge two bits at a time



